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9438 LOW LEVEL TRAVELING WAVE TUBE AMPLIFIER ANOMALY. TECHNICAL--ETC(U)

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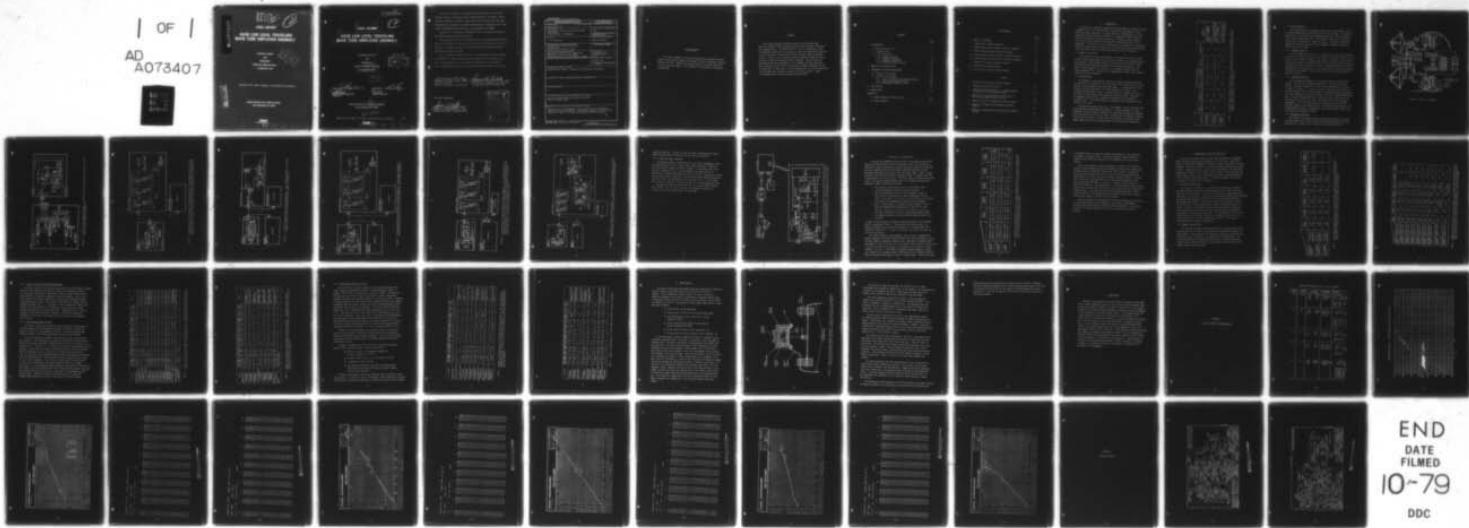
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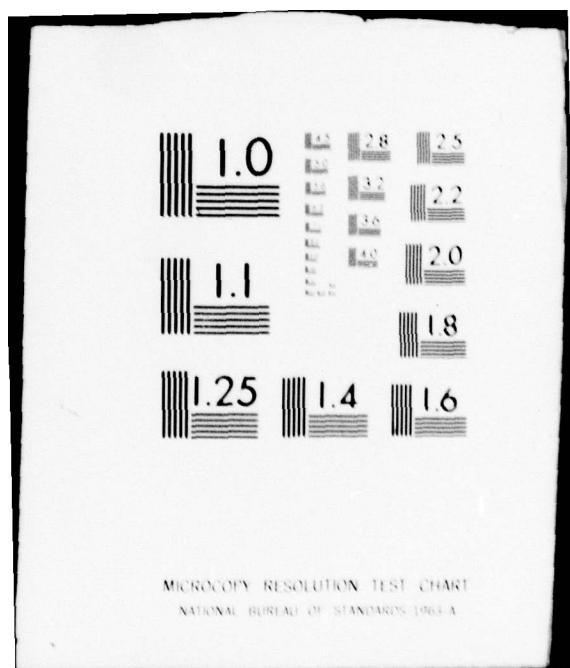
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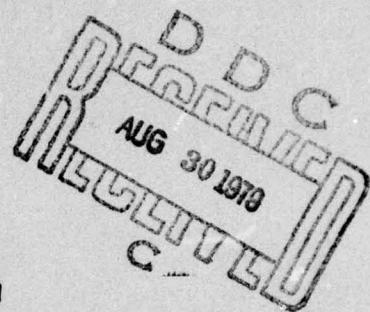
FINAL REPORT

**9438 LOW LEVEL TRAVELING
WAVE TUBE AMPLIFIER ANOMALY**

TECHNICAL REPORT
AND
APPENDICES

REPORT NO. 28600-AR-016-01

15 FEBRUARY 1978



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PREFACE

This report presents the 9438 Low-Level Traveling Wave Tube Amplifier (LLTWTA) anomaly investigation with the resulting conclusions and recommendations. The 9438 satellite is still in operation, using the redundant LLTWTA, and is providing all desired communications service. It was not possible to state definitively the exact cause of the 9438 failure. Rather, a set of candidate failure modes was identified which could have caused the observed failure signature. Each of these was examined during the investigation, and a judgment was made concerning the likelihood of such a failure occurring in LLWTAs scheduled for use on future DSCS II satellites. It was concluded that all of the identified failure modes were isolated in nature, not likely to recur. Hence, no recommendations are made concerning future LLWTAs.

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1. INTRODUCTION

A failure of a low-level traveling wave tube amplifier (LLTWTa) occurred in August 1977 on 777 Satellite 9438. A detailed investigation of this anomaly has been conducted. This investigation included analysis of telemetry data, failure simulation testing on a breadboard LLTWTa, review of past failure history, review of application, derating, and part testing of critical parts, review of the TWT heater configuration and critical dimensions. The results of this investigation are summarized in this report, along with conclusions as to the nature of the orbit failure and recommendations for future activities regarding LLTWTAs on the 777 satellites.

1.1 ANOMALY DESCRIPTION

On 28 August, at approximately 0700Z, DCA notified the STC that 9438 narrow coverage communications had been lost at 0650Z. An emergency support was scheduled. When telemetry became available (at 0723Z), it was noted that the NCLLTWTa-2 had low readings on all telemetry parameters. That amplifier was commanded OFF, then ON. All parameters had the same low values, whereupon the -1 amplifier was commanded ON at 0806Z. DCA reported communications were restored.

1.2 TELEMETRY DATA

No telemetry is available for the time at which the anomaly occurred. The data that is available for the failed TWTa - the last pass prior to the anomaly and the emergency pass after the anomaly - is summarized in Table 1. The data indicates decreases in all TWTa voltages and currents. The cathode current and helix current are probably zero, although the values in the table are those derived from telemetry calibration data. Obviously, the negative value for helix current is impossible, and it should be considered zero. It has been generally concluded that the cathode current really is zero, also.

The data does establish one fact: this anomaly is quite different from those previously encountered with HLTWTAs. In those anomalies, all TWTa parameters read zero counts, indicating the TWTa was off either by operation of an overcurrent trip circuit or due to a blown fuse (or possibly a failure of the turn-on circuit). In the case of the LLTWTa, at least part of the power supply circuits are receiving power and functioning to some extent.

TELEMETERED PARAMETERS						
TIME/DATE	INPUT CURRENT(MA)	CATHODE CURRENT(MA)	HELIX CURRENT(MA)	FILAMENT VOLTAGE(V)	HELIX VOLTAGE(V)	TEMPERATURE (°F)
28 AUGUST 0315-0330Z	193	5.35	0.046	3.913-3.977	1715-1741	90
						LAST PASS PRIOR TO ANOMALY. NOMINAL DATA.
28 AUGUST 0723-0804Z	72-82	0.165*	-0.027*	3.012-3.198	1646-1690	83
						FIRST DATA AVAILABLE AFTER ANOMALY. ENDS WITH OFF COMMAND.
28 AUGUST 0805Z	77	0.165*	-0.027*	3.033	1658	83
						DATA WHEN NCLLTWTA-2 WAS TURNED ON AGAIN.

Table 1. NCLLTWTA-2 Data, Before and After Anomaly. (The values for helix and cathode current are, in fact, taken to be zero. The non-zero values shown are due to bias and offset in the telemetry conditioning circuits in the TWTA.)

1.3 SYSTEM INTERFACES

The HLTWTA functions as the driver amplifier for the HLTWTAs in the EC and NC communications transmitters on the 777 satellite. An identical backup unit is provided for each operating amplifier, making a total of four LLTWTAs on each satellite. The functional location of the LLTWTAs within the 777 transponder is shown in Figure 1. The major interfaces between the satellite and the TWTAs are command, telemetry, structural, thermal, and primary power.

1.3.1 Command Interface

The ON command for the LLTWTA is a steady state +5 VDC signal supplied by the SLA. As shown in Figure 2, this signal is supplied from the 5 VDC output of the SLA converter through relay contacts in the SLA. Signal return for this ON command is through the TWTAs, SLA, and despun platform structure. It should be noted that the only circuitry in the SLA peculiar to an individual TWTAs are the two printed circuit board traces and one wire connecting that TWTAs to the common +5 VDC source used to provide the ON command voltage for all TWTAs.

1.3.2 Telemetry Interface

Five telemetry measurements are available from each LLTWTA; input current, helix voltage, filament voltage, helix current, and cathode current. Interface schematics for each of these measurements are shown in Figures 3 through 7. It should be noted at this point that the helix current, cathode current, helix voltage and filament voltage measurements are cross-strapped in the satellite harness with the corresponding measurement from the redundant amplifier. Since only one of each pair of redundant amplifiers is on at a time, the effect of this cross-strapping arrangement is to place a parallel passive resistive load across the telemetry output of the operating tube. The effect of this parallel load on measurement accuracy is accounted for when the telemetry circuits are calibrated by the amplifier vendor.

1.3.3 Mechanical Interface

The LLTWTAs are mounted to the satellite platform with four screws inserted through feet at the corners of the amplifier chassis into platform inserts. A layer of RTV is applied to the platform prior to

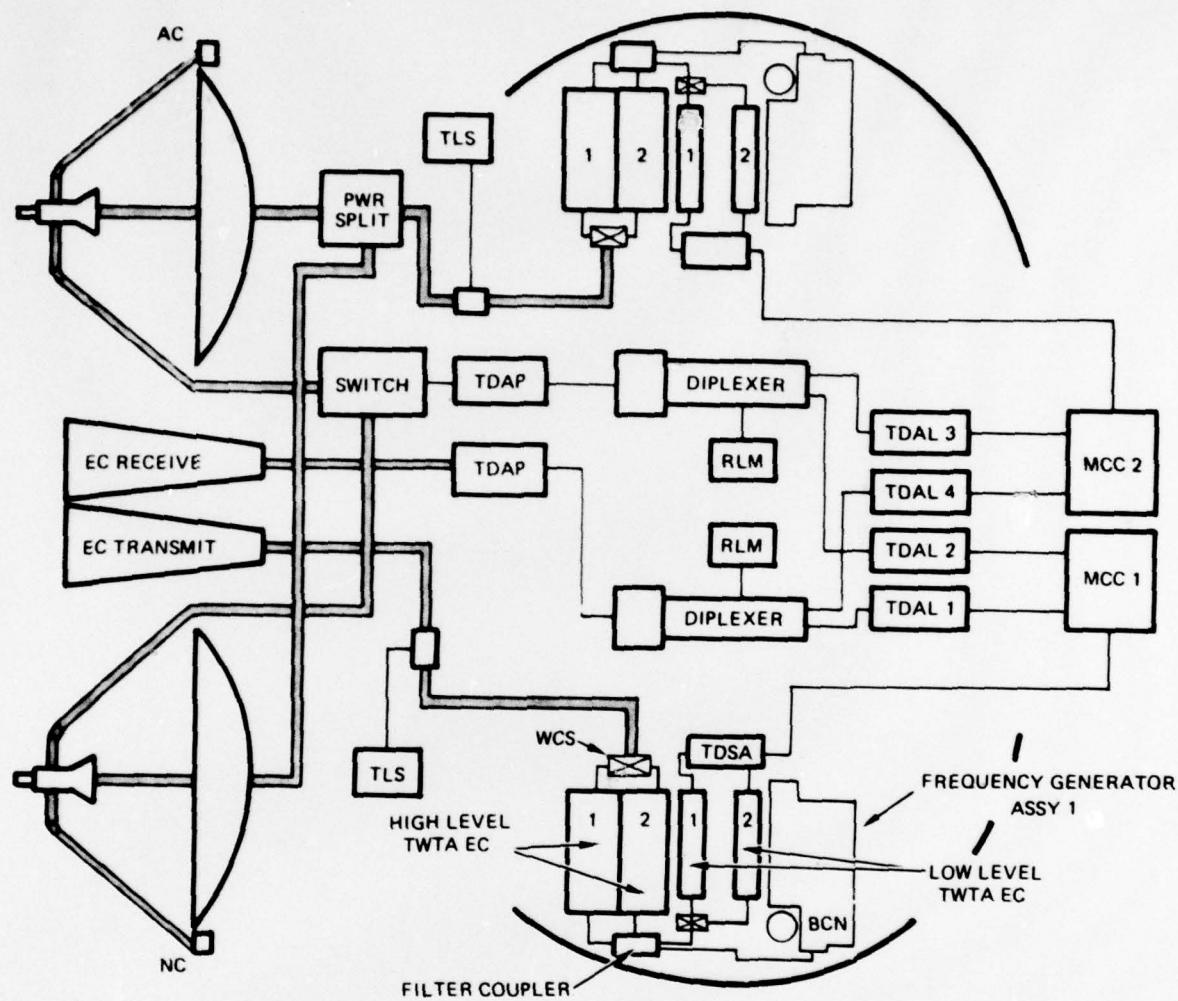


Figure 1. DSCS II Transponder

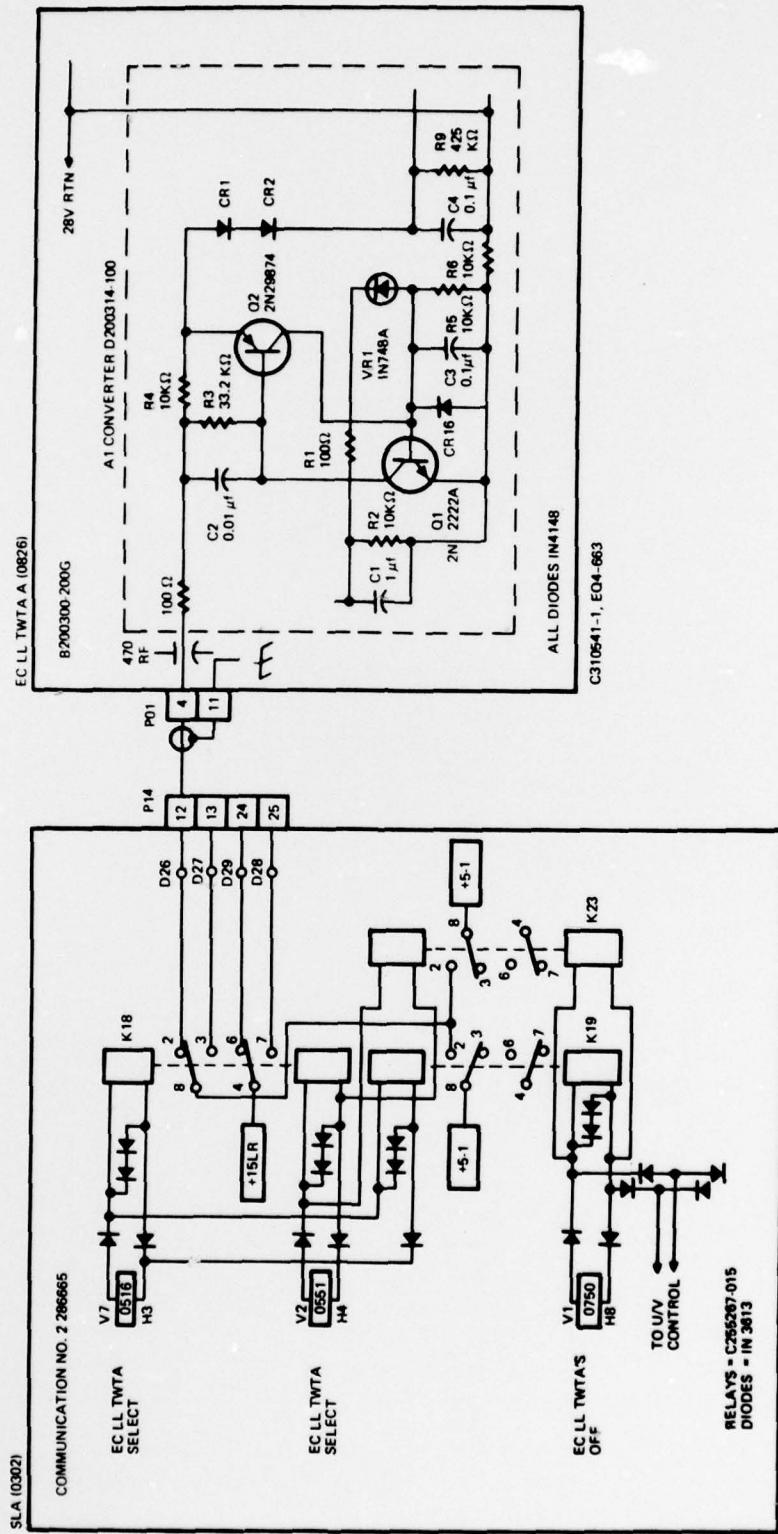


Figure 2. LLT WTA Turn-On Command Interface. (A steady state 5 VDC signal from the SLA is used to turn on each LLT WTA individually.)

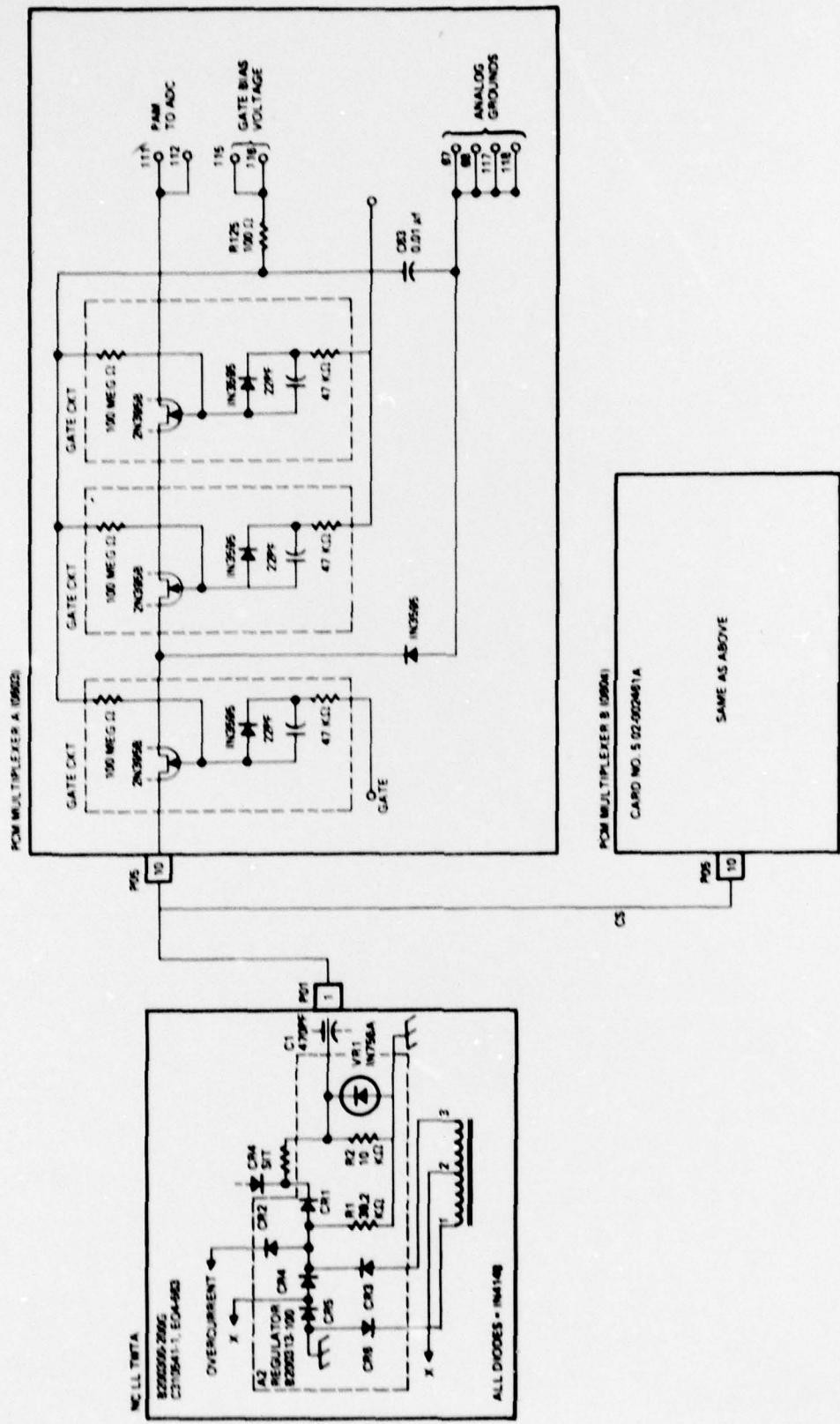


Figure 3. LLTWA Input Current Telemetry Interface Schematic. (A saturable reactor is used to measure TWTa input current and generate an overcurrent signal. The overcurrent signal is used to trigger a trip circuit (not shown) which shuts down the TWTa.)

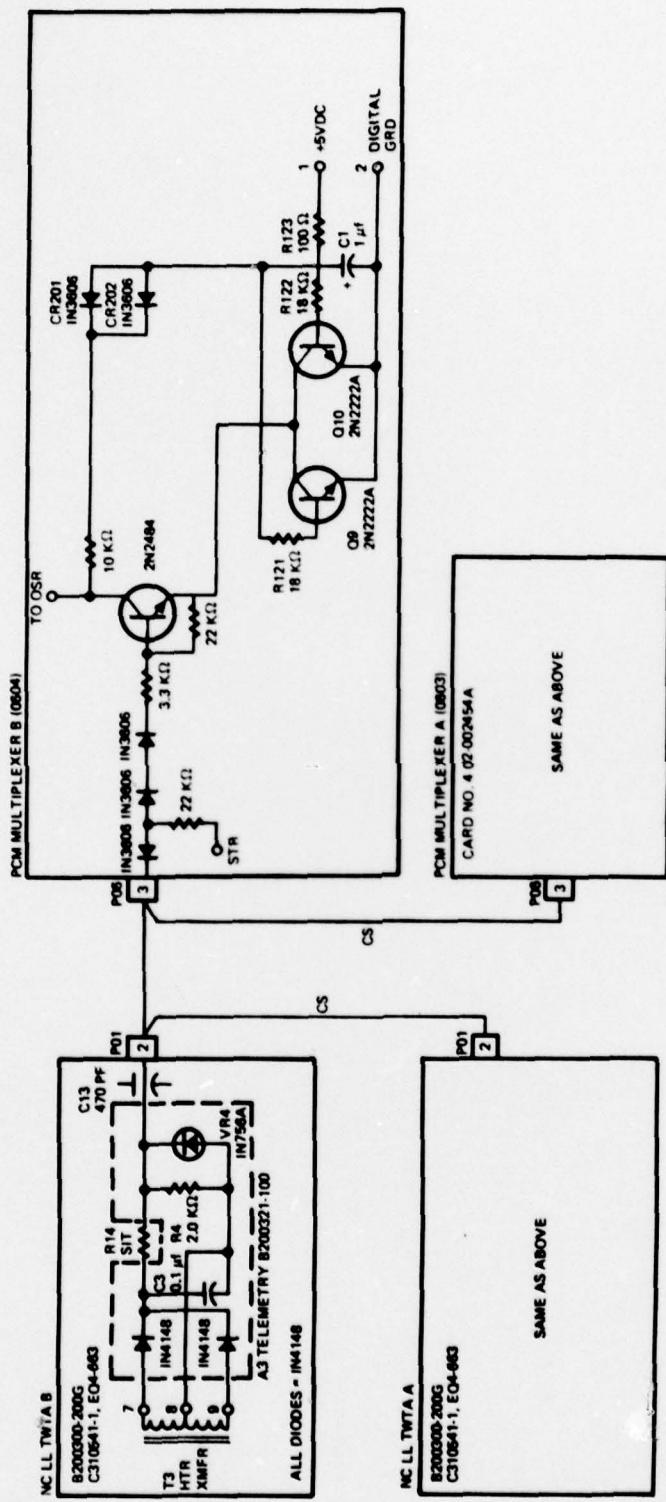


Figure 4. LLTWTA Filament Voltage Interface Schematic. (The filament voltage is measured indirectly using an auxiliary winding on the heater transformer.)

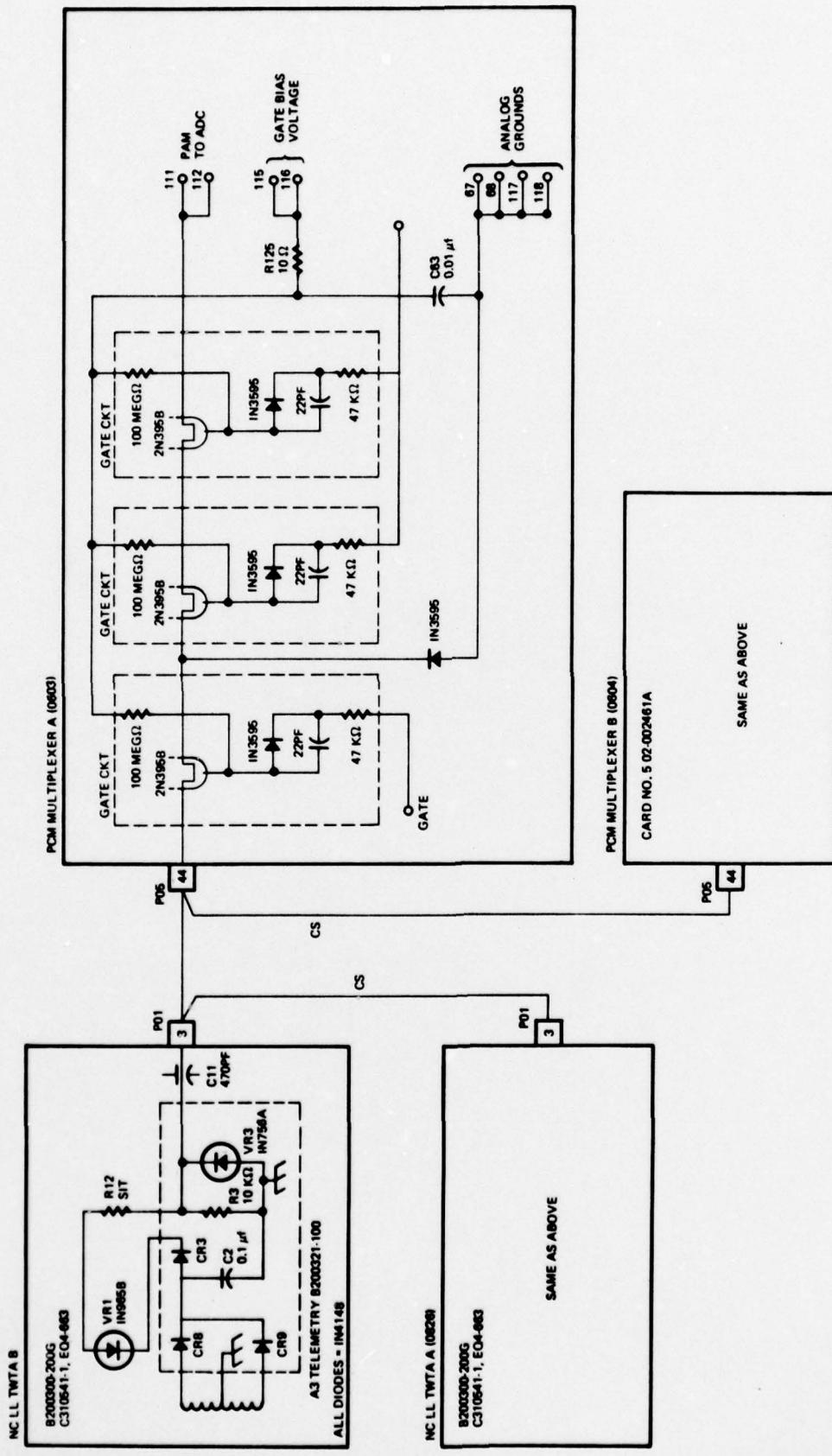


Figure 5. LLT WTA Cathode Voltage Telemetry Interface Schematic. (The cathode voltage is measured indirectly using an auxiliary winding on the high voltage transformer.)

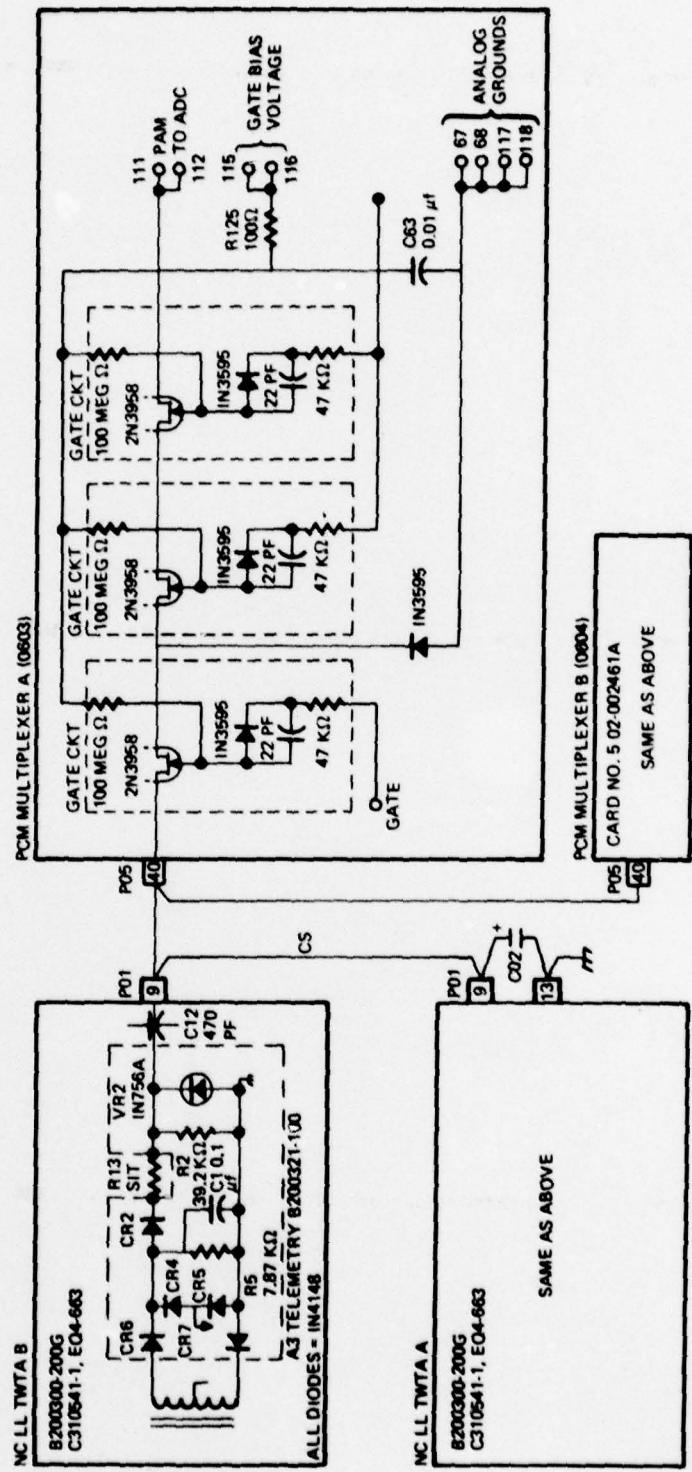
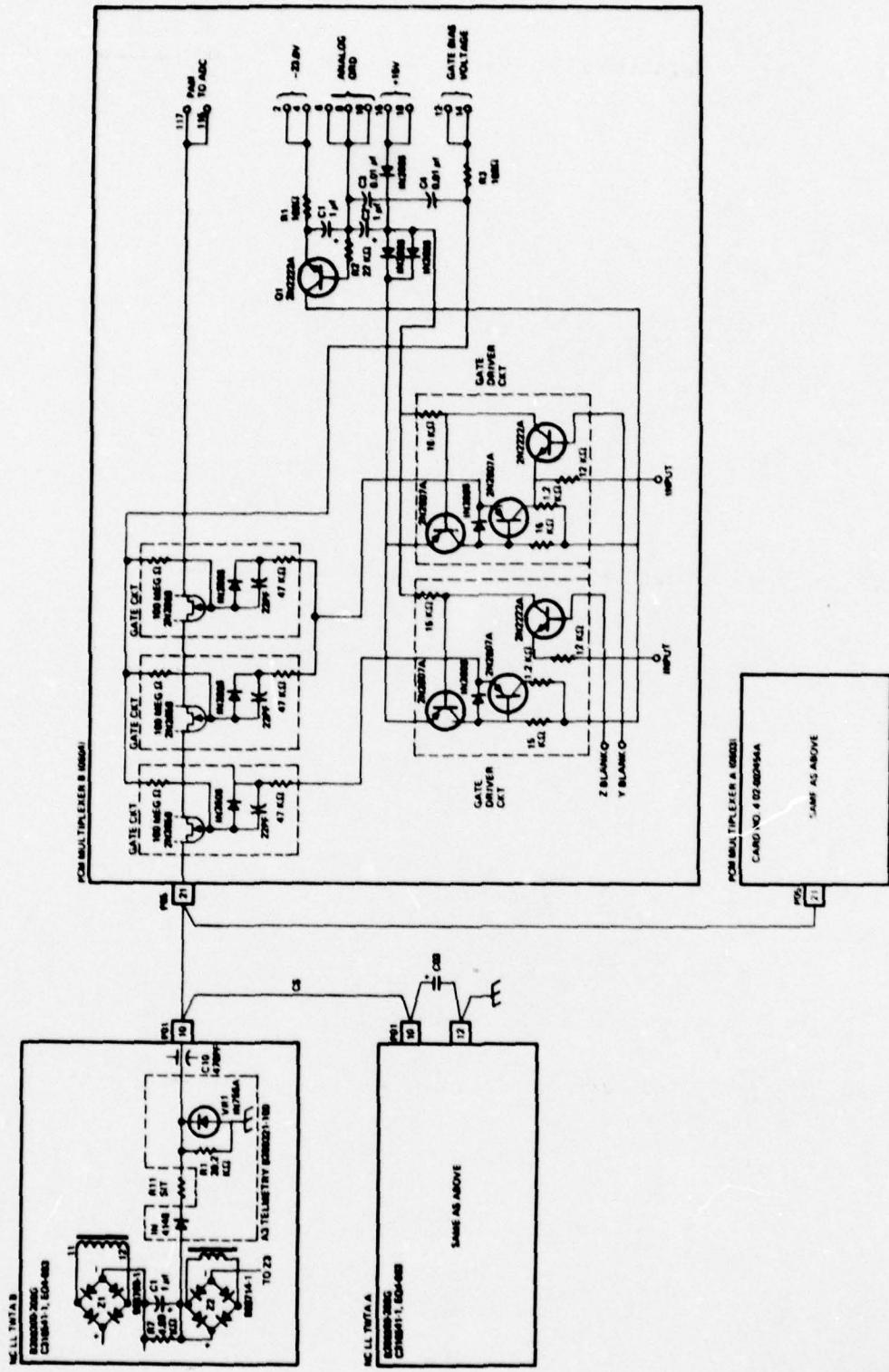


Figure 6. LLTWA Cathode Current Telemetry Interface Schematic. (The cathode current is measured using a saturable reactor in the cathode voltage output section of the high voltage module. A capacitor is installed in the harness to reduce the magnitude of noise spikes on the TWT A telemetry output.)



installing the TWTA. The RTV is used to insure intimate thermal contact between the baseplate of the TWTA and the satellite platform.

1.3.4 Electrical Power Interface

Fused primary power is distributed to each LLT WTA independently from the Power Distribution Unit (PDU) on the spinning platform. Details of this distribution scheme are shown in Figure 8. The primary power from the PCU is regulated at 32.4 ± 0.2 VDC whenever the satellite is in sunlight not recharging the batteries after an eclipse. During each eclipse and for several hours thereafter, the primary bus goes through one voltage cycle from 32.4 V to approximately 26 V and back to 32 V. This voltage cycle occurs 45 times in one eclipse season, two eclipse seasons per year.

The nominal primary current load at 32.4 V is approximately 190 mA for a LLT WTA. The slip rings are rated for continuous operation at 3 A each. Two are used in parallel for each TWTA.

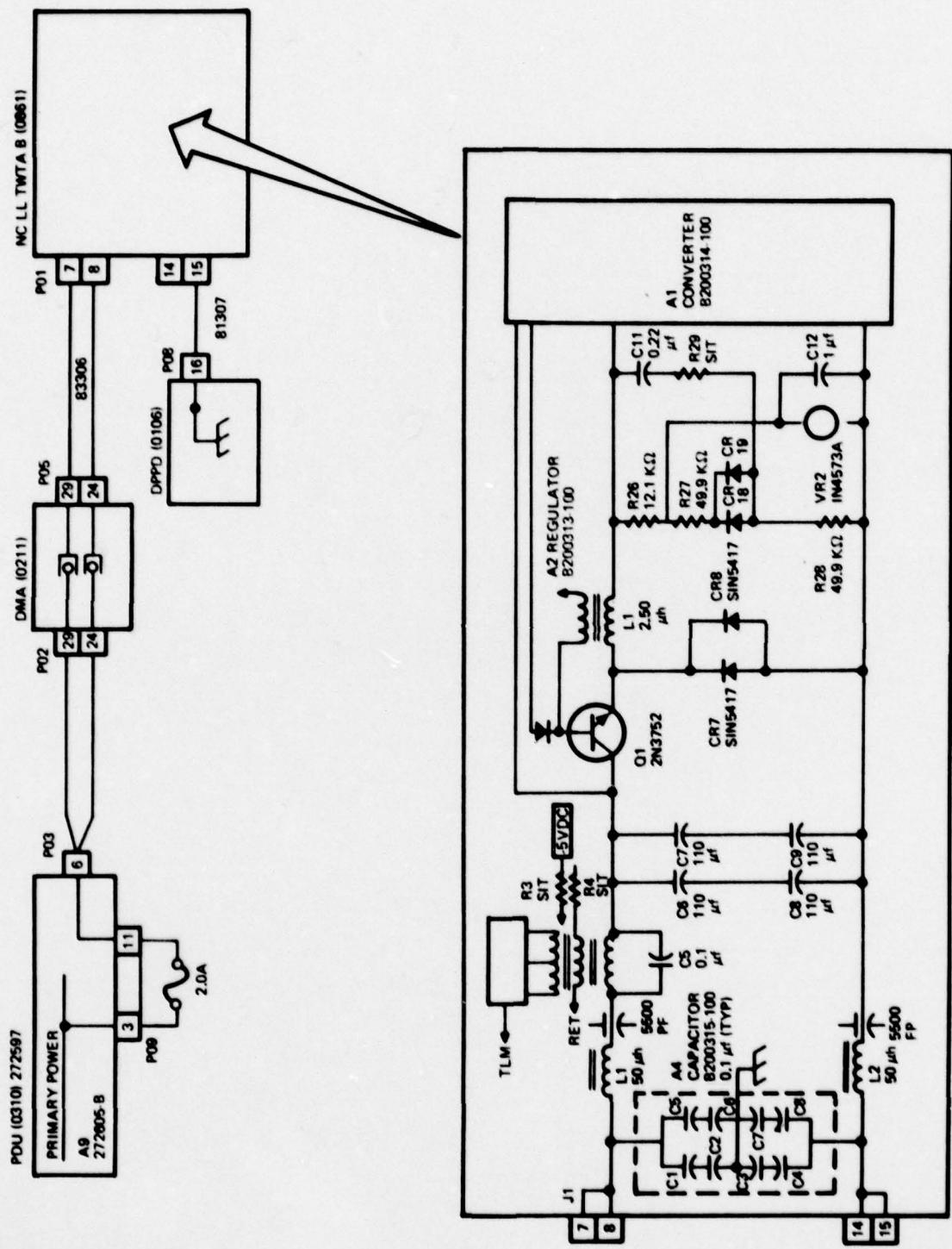


Figure 8. LLTWTA Primary Power Interface. (Primary power is supplied to each individual LLTWTA through a 2 A fuse and two parallel slip rings.)

2. ANALYSIS OF TELEMETRY DATA

The amplifier parameters given in Table 1 are direct copies of the numerical values derived from the calibration curves in use at the SCF. Calibration curves are derived from ones used during satellite integration which are themselves derived from vendor supplied calibration curves developed during factory testing of the TWT power supply. Also, it must be kept in mind that the satellite telemetry system is a digital one with a quantization of 20 mV per count. The factors which can obscure the actual value of the measured TWT parameter when it is deduced from satellite telemetry voltages include the following:

1. The telemetry conditioning circuits in the TWT's have a slightly temperature sensitive transfer function.
2. Only one calibration curve for each parameter is used in the satellite calibration file during Integration and Test (I&T). This curve is an average one drawn approximately through the center of the temperature spread for each parameter.
3. Only a limited amount of computer storage capacity is available for telemetry calibrations both in the I&T file and the SCF. Hence, some compromises are required in matching the stored calibration curves to the measured vendor curves.
4. The quantizing factor of the satellite telemetry system is 20 mV/count.

In light of these factors a telemetry uncertainty analysis was performed which is presented in Table 2. The detailed calibration curves, and computer equivalents are contained in Appendix A. An additional entry included in Table 2 is a listing of the change in telemetry voltages and associated parameters.

An initial analysis of the telemetry data in Table 2 indicated the heater voltage on the TWT had fallen sufficiently to stop cathode emissions. The small amount of apparent cathode current indicated by telemetry after the anomaly is due to the fact that the cathode current telemetry conditioning circuit in the TWT has an output of approximately 2.0 V when the cathode current is in fact 0. The change in cathode voltage telemetry is caused by a change in the telemetry signal conditioning circuit transfer function when the cathode current goes to zero or slightly above. This circuit uses

	INPUT CURRENT	FILAMENT VOLTAGE	CATHODE VOLTAGE	CATHODE CURRENT	HELIX CURRENT
S/N 24-19 Nominal					
Telemetry Voltage Parameter Value	2.54 to 2.58v 180 to 188 ma	4.18 to 4.22v 3.88 to 3.92v	2.26 to 2.46v -1711 to -1745v	3.58 to 3.62v 5.3 to 5.45ma	0.42 to 0.46v 0.04 to 0.06ma
S/N 24-19 Anomaly					
Telemetry Voltage Parameter Value	2.06 to 2.14v 30 to 110 ma	2.90 to 3.12v 3.0 to 3.22v	1.82 to 1.14v -1643 to -1699v	1.98 to 2.02v 0.1 to 0.15ma	0.16 to 0.20v 0 ma
Δ from Normal					
Telemetry Voltage Parameter Value	-.48 to -.44v -158 to -70ma	-.28 to -.10v -.92 to -.66v	-.44 to -.32v +102 to +16v	-.160v -5.35 to -5.15ma	-.026v -.04 to -.06ma

Table 2. Telemetry Uncertainty Analysis. (For a given telemetry voltage, an analysis was performed of the maximum and minimum parameter value which could exist. Significant variations can be seen in input current and filament voltage.)

a saturated reactor to sense the cathode voltage which is also sensitive to changes in cathode current. Hence, the apparent slight reduction in cathode current after the anomaly can be explained by the loss of beam current.

Due to the redundant current measurements included in the satellite system, it was possible to obtain an independent check that an anomaly had occurred within the TWTA which reduced its input current. The main bus current monitor measures the total satellite load being supplied by the Power Control Unit (PCU), exclusive of battery charging current. The data from this monitor confirmed that the bus load had been reduced by 70 to 120 ma after the TWTA anomaly. Further, it showed a similar decrease when the NCLLTWTA No. 2 was commanded off. The uncertainty in these changes is due to the quantizing of the main bus current monitor which is 60 ma per telemetry count. This data did confirm the apparent reduction in TWTA input current after the anomaly and the approximate value of the residual current being drawn by the TWTA after the anomaly.

The main emphasis of the subsequent failure investigation was directed at identifying specific failure modes in the TWT power supply heater circuit which could produce the observed failure signature. This circuit consists of a linear regulator and a DC to AC converter, plus the TWT filament.

3. BREADBOARD TESTING AND SIMULATION

A series of failure simulation tests were performed on a breadboard model of the TWT power supply operating with a TWT load. During the course of these tests attempts were made to recreate the telemetry voltage signature of the orbit failure by simulating various external and internal failures. Opens and shorts of various active components within the power supply were simulated. Also certain partial short circuit (overload) and partial open circuit (series resistance) faults were simulated both within and external to the power supply. A schematic diagram of the LLTWTa is included in Appendix B for reference.

3.1 EXTERNAL FAILURE MODES

As discussed in Section 1.3, the LLTWTa has two primary interfaces with the satellite electrical system whose malfunction could cause mis-operation of the amplifier. The first of these is the command interface; the second, primary power. The tests on the command interface were performed by reducing the command voltage from 5 V to the point where anomalous performance was observed. The results of this test are given in Table 3. As can be seen, it was not possible to reproduce the orbit anomaly signature. The tests on the power interface were performed by inserting a series resistance in series with the primary power source to the TWTa and gradually increasing the resistance. This was done to simulate a possible slip-ring failure where the series resistance of the slip ring increases with time. This test, summarized in Table 4, also did not reproduce the orbit anomaly characteristic.

3.2 INTERNAL FAILURE MODES

The internal failure mode testing was done in several phases, using data from the initial tests to indicate more refined follow-up tests to be performed. This report will not attempt to trace this chronology, but will discuss the test results on a functionally allocated basis. The tests were primarily concerned with three areas: TWT and associated wiring faults, failures of the high voltage module, and failures of the heater voltage linear regulator.

		INPUT CURRENT	FILAMENT VOLTAGE	CATHODE VOLTAGE	CATHODE CURRENT	HELIX CURRENT	SWITCHING REGULATOR	LINEAR REGULATOR
BREADBOARD NOMINAL	TELEMETRY PARAMETER	1.66 188ma	3.91 3.90v	2.23 -1730v	3.62 5.3ma	0.82 .186ma	1869v	17.37v
LOW COMMAND VOLTAGE (1.15v)	TELEMETRY PARAMETER	3.60 280ma	3.91 3.93v	2.22 -1730v	3.50 5.4ma	0.849 0.18ma		
LOW COMMAND VOLTAGE (1.1v)	TELEMETRY PARAMETER	7.82 430ma	3.92 3.94	3.84 -1996	4.33 6.0ma	3.43 0.83ma		

Table 3. Performance Characteristics of a LLTWA Subjected to Application of Low Command Voltage.
(The command voltage threshold for nominal LLTWA power supply operation is slightly above 1.15 v. Below this value, the TWTA draws excessive input current.)

BREADBOARD NOMINAL	INPUT CURRENT	FILAMENT VOLTAGE	CATHODE VOLTAGE	CATHODE CURRENT	HELIX CURRENT	SWITCHING REGULATOR	LINEAR REGULATOR
BREADBOARD TELEMETRY PARAMETER VALUE	1.66v 188ma	3.91v 3.90v	2.23v -1730v	3.62v 5.3ma	0.82 .186ma		
27 Ω SERIES RESISTANCE PARAMETER VALUE (22.3v)	TELEMETRY VOLTAGE PARAMETER VALUE	3.65v 350ma	3.91v 3.9v	2.22v -1730v	3.51v 5.3ma	0.790 .0180ma	
29 Ω SERIES RESISTANCE PARAMETER VALUE (21.6v)	TELEMETRY VOLTAGE PARAMETER VALUE	3.78v 360ma	3.91v 3.9v	2.22v -1730v	3.51v 5.3v	.798v .180ma	+254v
34 Ω SERIES RESISTANCE PARAMETER VALUE (18.7v)	TELEMETRY VOLTAGE PARAMETER VALUE	4.24v 390ma	3.92v 3.9v	2.21v -1723v	3.51v 5.3ma	.803v .18ma	-1263v
40 Ω SERIES RESISTANCE PARAMETER VALUE (17.4v)	TELEMETRY VOLTAGE PARAMETER VALUE	3.52v 360ma	3.79v 3.6v	1.42v -1598v	3.18v 4.65ma	.890v .21ma	+254v
45 Ω SERIES RESISTANCE PARAMETER VALUE (16.65v)	TELEMETRY VOLTAGE PARAMETER VALUE	3.05v 340ma	3.61v 3.2v	1.08v -1539v	3.01v 4.34ma	.673v .158ma	-1165v
50 Ω SERIES RESISTANCE PARAMETER VALUE (15.94v)	TELEMETRY VOLTAGE PARAMETER VALUE	2.75v 320ma	3.44v 3.0v	.762v -1482v	2.84v 4.05ma	.495v .11ma	-1124v
55 Ω SERIES RESISTANCE PARAMETER VALUE (15.3v)	TELEMETRY VOLTAGE PARAMETER VALUE	2.52v 300 ma	3.28v 3.0v	.449v -1426v	2.67v 3.7ma	.430v .10ma	-1045v
60 Ω SERIES RESISTANCE PARAMETER VALUE (14.7v)	TELEMETRY VOLTAGE PARAMETER VALUE	2.31v 285ma	3.14v 3.0v	.017v -1349v	2.34v .26ma	1.00v .27ma	-982v
					+Dropping +Climbing	+Dropping	+197

Table 4. Operation of LLTWA with Series Resistance in the Primary Power Distribution Lines.
(With a series resistance greater than approximately 25 Ω , the LLTWA power supply
input current increases, while the filament voltage is relatively unchanged.)

3.2.1 Faults in the TWT and Associated Wiring

A series of tests of various opens and shorts of the TWT heater, cathode, and helix were conducted, the results of which are presented in Table 5. As can be seen from the data summarized in Table 5, none of these failure modes appeared to match the signature of the orbit anomaly. One or more of the resultant telemetry readings was significantly different from the corresponding orbit value. The closest failure mode was a heater short of somewhere between 5 and 7 Ω . The change in input current was close to the minimum value indicated by orbit telemetry, and the change in filament voltage telemetry close to the maximum value. Because of this, a specific review was performed of the heater geometry. The review, summarized elsewhere in this report, concluded this type of partial short appeared very unlikely.

3.2.2 High Voltage Module Failures

The results of the tests performed simulating various failure modes in the power supply high voltage module are given in Table 6. As with the results of the fault tests reported in Table 5, no failure mechanism was tested that gave a very close approximation to the F8 orbit anomaly.

Two failure modes were, however, tantalizingly close to matching the orbit anomaly. These two modes occur when one of the high voltage rectifier diodes in the heater converter is replaced with a small (3 Ω) resistor or is shunted by a 3 Ω resistor; i.e., CR1 or CR2 in the high voltage module partially shorted. In this case, the input current drops almost as much as indicated by orbit telemetry (67 ma in test versus a minimum of 70 ma in orbit). Also, the filament voltage telemetry becomes grossly inaccurate (an indicated value of approximately 2 V from calibration curves, versus an actual value of .38 to .46 V measured). This is due to distortions of the wave shape of the filament voltage when one output rectifier diode is no longer rectifying. This wave shape distortion depends on the degree of saturation of the filament voltage transformer with CR1 or CR2 partially shorted, and would vary greatly from unit to unit and as a function of the impedance of the shorted diode. Therefore, a partial short of CR2 or CR1 in the high voltage module cannot be ruled out as the cause of the orbit anomaly.

FAILURE MODE	INPUT CURRENT	FILAMENT VOLTAGE	CATHODE VOLTAGE	CATHODE CURRENT	HELIX CURRENT	SWITCHING PARAMETER	LINEAR REG. VOLTAGE	REMARKS
	TLM VOLT	TLM PARAMETER VOLT	TLM VOLT	TLM PARAMETER VOLT	TLM VOLT	TLM PARAMETER VOLT	TLM VOLT	
BREADBOARD NOMINAL	1.66	188 mA	3.91 V	2.23 -1730 V	3.62 5.3 mA	0.82 .186 mA	18.69 V	17.37 V
HEATER ON, E. DISCONNECTED	1.28	108 mA	3.72 -.19 V	1.76 -1727 V	1.90 0 mA	.18 0 mA	16.87 V	16.4 V HEATER VOLTAGE TOO HIGH
△ FROM NOMINAL								
HV ON, FILAMENT DISCONNECTED	1.20	74 mA	5.63 -.72 V	8.26 4.36 V	1.78 -1728 V	1.91 0 mA	.18 0 mA	16.83 V
△ FROM NOMINAL								
HV & FILAMENT DISCONNECTED	1.21	75 mA	5.63 8.3 V	1.79	-1729 V	1.91 0 mA	.18 0 mA	16.83 V
HEATER SHORTED 0 ~	1.38	128 mA	2.44 0 V	1.99 -1726 V	1.99 0 mA	.18 0 mA	17.41 V	4.1 V INPUT CURRENT TO HIGH, HEATER VOLTAGE TOO LOW
△ FROM NOMINAL	-28	-60 mA	-1.47 -3.90 V					
HEATER SHORTED 5 ~	1.39	127 mA	2.73 1.61 V	2.00 -1726 V	1.97 .006 mA	.20 .007 mA	17.39 V	9.89 V INPUT CURRENT TOO HIGH
△ FROM NOMINAL		-67 mA						
HEATER SHORTED 7 ~	1.47	159 mA	2.99 2.07 V	1.82 -1740 V	1.99 .036 mA	.32 .04 mA	17.17 V	11.36 V INPUT CURRENT TOO HIGH
△ FROM NOMINAL	-29	-29 mA						
HEATER SHORTED 10 ~	1.66	181 mA	3.24 2.24 V	2.19 -1727 V	2.48 .78 mA	2.15 .51 mA	N/A	13.77 V INPUT CURRENT TOO HIGH
△ FROM NOMINAL	-7	-7 mA						
HEATER SHORTED 20 ~	1.74	219 mA	3.95 3.77 V	2.21 -1729 V	3.61 5.3 mA	.85 .195 mA	N/A	17.35 V INPUT CURRENT TOO HIGH
△ FROM NOMINAL	+31	+31 mA						
HELIX/HEATER SHORT (100K Ω)	7.87	1.88 a	3.94 3.0 V	2.48 -1639 V	8.08 4.9 mA	7.99 .23 mA	N/A	INPUT CURRENT TOO HIGH
△ FROM NOMINAL	+1.69 a	+1.69 a						
HELIX/HEATER SHORT (200K Ω)	7.88	1.02 a	3.94 3.0 V	2.37 -1735 V	6.64 5.5 mA	7.95 .175 mA	N/A	INPUT CURRENT TOO HIGH
△ FROM NOMINAL	+83 a	+83 a						
60 Ω RESISTANCE IN CATHODE	2.31	N/A	3.14 3.0 V	.017	-1349 V	2.34 .26 mA	1.00 .27 mA	CATHODE VOLTAGE TOO HIGH
- LEAD								
15 Ω RESISTANCE IN SERIES	1.28	100 mA	3.93 3.76 P.S.	1.70 -1731 V	1.90 0 mA	.19 0 mA	17.32 V	17.00 V HEATER VOLTAGE TOO HIGH
△ WITH HEATER								
△ FROM NOMINAL		-88 mA	1.43 TWT					

Table 5. Summary of TWT Failure Modes and Effects Testing. (The tested failure modes did not yield a significantly close failure signature to the observed post-failure orbit data.)

FAILURE MODE	INPUT CURRENT		FILAMENT VOLTAGE		CATHODE VOLTAGE		CATHODE CURRENT		HELIX CURRENT		SWITCHING REG. VOLTAGE	LINEAR REG. VOLTAGE	REMARKS
	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VOLT	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE	TLM VOLT	PARAMETER VALUE			
BREADBOARD NOMINAL	1.66	188 mA	3.91	3.90 V	2.23	-1730 V	3.62	5.3 mA	0.82	.186 mA	18.69 V	17.37 V	
CR1 OR CR2 OPEN △ FROM NOMINAL	1.66	185 mA	4.93	3.64 V	2.18	-1728 V	3.63	5.15 mA	.912	.196 mA	18.85 V	17.36 V	INPUT CURRENT & HEATER VOLTAGE TOO HIGH
CR1 OR CR2 SHORT △ FROM NOMINAL	1.43	131 mA	2.03	0 V	1.99	-1726 V	2.00	0 mA	0.18	0 mA	17.38 V	2.0 V	FILAMENT VOLTAGE TOO LOW
CR1 AND CR2 OPEN △ FROM NOMINAL	.994	N/A	5.79	0 V	2.07	-1734 V	1.87	0 mA	.248	0 mA			FILAMENT VOLTAGE TELEMETRY TOO HIGH
3.7- RESISTANCE IN PLACE OF CR2 △ FROM NOMINAL	1.35	121 mA	3.02	.38 V	1.85	-1723 V	1.98	0 mA	.25	0 mA	17.28 V	5.08 V	INPUT CURRENT & FILAMENT VOLTAGE TELEMETRY SLIGHTLY HIGH
24.7- RESISTANCE IN PARALLEL CR2 △ FROM NOMINAL	1.77	209 mA	4.53	3.0 V	2.18	-1728 V	2.87	1.7 mA	.68 mA	18.85 V	14.24 V	INPUT CURRENT & FILAMENT VOLTAGE TELEMETRY TOO HIGH	
3.7- RESISTANCE IN PARALLEL CR2 △ FROM NOMINAL	1.35	121 mA	3.00	.46 V	1.83	-1723 V	1.97	0 mA	.23	0 mA	17.27 V	5.03 V	INPUT CURRENT & FILAMENT VOLTAGE TELEMETRY SLIGHTLY HIGH
OPEN CB △ FROM NOMINAL	1.67	190 mA	4.03	3.91 V	2.22	-1722 V	3.66	5.35 mA	.87	.18 mA	18.66 V	17.36 V	INPUT CURRENT TO FILAMENT VOLTAGE TOO HIGH
SHORT CB	SAME AS SHORTED HEATER												

Table 6. Summary of HV Module Failure Modes and Effects Testing. (One tested failure mode, partial short of CR1 or CR2, does provide a reasonable, although not exact, replication of the orbit failure signature.)

3.2.3 Semiconductor Module Failures

The final group of failure simulation tests were performed on the linear regulator and telemetry boards in the semiconductor module. A summary of the results of these tests is given in Table 7. As with the previous two sets of tests, none of the specific failure simulations yielded a characteristic signature identical to the one in orbit. However, it becomes apparent that the orbit failure signature could be very closely reproduced under the condition where the heater voltage decreased to the point where the TWT beam is extinguished. A test of three similar TWTs showed that this occurred when the heater voltage was at 2.6, 2.85, and 2.9 V. The heater voltage in the flight TWTA is indicated to be as low as 2.70 V by telemetry. Thus, this data is consistent with the hypothesis that the beam has been extinguished in the flight TWT by a failure in the linear regulator which has reduced the heater voltage to 2.7 to 3.0 V. This level of heater voltage would exist if the series regulator output voltage had been reduced to about 13 V from its nominal value of 17.5 V.

A specific failure mode which did not appear likely is an open or short of the transistors (A1-Q10 and A1-Q11) used to drive the primary windings of the heater high voltage transformer. The test results showed this type of failure produced grossly different symptoms from the one experienced in orbit.

A number of component failures could reduce the linear regulator output to the signatured values. These can be listed:

- A shift in value of semiconductor module SIT R6 from a nominal $5\ \Omega$ to $10\ \Omega$
- A partial short (50 to $75\ \Omega$) of A2-CR20 or A2-CR21
- A reduction in gain in A2-Q2
- Any failure in the sense and control circuitry which controls A2-Q2 and hence regulates the output voltage of the linear regulator.

The most likely parts in the linear regulator are the elements in the pass circuit; i.e., the first three listed above. Hence, these were selected for additional investigation described in subsequent sections of this report.

FAILURE MODE	INPUT CURRENT TLM VOLT	FILAMENT VOLTAGE TLM PARAMETER VOLT	CATHODE VOLTAGE TLM PARAMETER VOLT	CATHODE CURRENT TLM PARAMETER VOLT	HELIX CURRENT TLM PARAMETER VOLT	SWITCHING REG. VOLTAGE	LINEAR REG. VOLTAGE
BREADBOARD NOMINAL	1.66	188 mA	3.91	3.90 v	2.23	-1730 v	3.62
BASE/EMITTER SHORT A1-Q10	3.56	N/A	3.76	3.7 v	2.189	-1727 v	3.37
COLLECTOR/EMITTER SHORT A1-Q11 Δ FROM NOMINAL	1.40	149 mA -.26	0 -3.91	0 -3.90 v	1.75	-1726 v	1.93
EMITTER OPEN A1-Q11 Δ FROM NOMINAL	1.78	227 mA +.12	7.74 +3.83	3.27 v -.63 v	2.18	-1729 v	3.42
SHORT OF A2-R35 (0.Δ) Δ FROM NOMINAL	1.25	91 mA -.41	1.21 -2.70	1.02 v -2.88 v	1.81	-1733 v	1.91
200K SHORT OF A2-R35 Δ FROM NOMINAL	1.65	168 mA -.01	3.06 -.85	3.02 v -.88 v	2.21	-1731 v	2.88
PARTIAL SHORT A2-CR20 (79.Δ in 11) Δ FROM NOMINAL	1.61	151 mA -36 mA	2.92	2.90 v	2.19	-1729 v	2.70
PARTIAL SHORT A2-CR20 (51.Δ in 11) Δ FROM NOMINAL	1.27	103 mA	1.47	1.29 v	1.73	-1729 v	1.93
PARTIAL SHORT A2-C16 (196.Δ in 11) Δ FROM NOMINAL	1.77	212 mA +24 mA	3.05 -.90 v	3.00 v -.90 v	2.18	-1728 v	2.91

Table 7. Summary of Semiconductor Failure Modes and Effects Testing. (Failure modes which reduced the linear regulator output to approximately 13 v would cause the TWT beam to be extinguished. This type of failure is consistent with the characteristics of the orbit anomaly.)

FAILURE MODE	INPUT CURRENT TLM VOLT	FILAMENT VOLTAGE TLM VOLT	CATHODE VOLTAGE TLM VOLT	PARAMETER VALUE	TLM PARAMETER VOLT	CATHODE CURRENT TLM VOLT	HELIIX CURRENT TLM VOLT	SWITCHING PARAMETER VALUE	LINEAR REG. VOLTAGE
OPEN A3-CR10 △ FROM NOMINAL	1.67	190 ma +2 ma	3.83	3.94 v +.04 v	2.22	-1732 v	3.66	5.4 ma +.1 ma	.855 .006ma
SHORTED A3-CR10 △ FROM NOMINAL	1.40	148 ma 40 ma	.242	0.47 v -3.43 v	1.75	-1728 v	1.93	0 ma	.240 0 ma
PARTIALLY SHORTED A3-CR10 (28.7 in 11)	1.81	226 ma	3.00	3.15 v	2.13	-1723 v	3.18	2.75 ma	3.01 .76 ma
SHORTED A3-C3 △ FROM NOMINAL	1.40	130 ma -58 ma	.032	0.92 v -2.98 v	2.0	-1728 v	2.0	0 ma	.243 0 ma
PARTIALLY SHORTED A3-C3 (16.7 in 11) △ FROM NOMINAL	1.77	228 ma +40 ma	3.00	3.71 v -.19 v	2.19	-1728 v	3.63	5.7 ma	.921 .20 ma
DEGRADED GAIN SCM-Q2 (1180.7 in 11 B-E) △ FROM NOMINAL	1.58	147 ma -41 ma	2.89	2.92 v	2.14	-1724 v	2.60	1.6 ma	2.38 .6 ma
CHANGE IN VALUE SCM-R6 (10.7) △ FROM NOMINAL	1.56	148 ma -40 ma	2.92	2.89 v -1.01 v	2.19	-1728 v	2.59	1.38 ma	2.46 .64 ma
CHANGE IN VALUE SCM-R6 (15.7) △ FROM NOMINAL	1.26	91 ma -97 ma	1.53	1.36 v -2.54 v	1.76	-1728 v	1.91	0 ma	.254 0 ma

Table 7. Summary of Semiconductor Failure Modes and Effects Testing (Continued)

4. PARTS REVIEW

The analysis and testing performed during the investigation identified certain specific parts which could be the source of the F8 orbit anomaly. Each of these was viewed in detail in order to attempt to reach an assessment as to relative likelihood of occurrence and the likelihood that a similar failure or failures could be expected in the LLTWTAs on inventory for F9-F12. The potential failure modes identified for review were the following:

- Partial short of the TWT heater
- Partial short of CR1 or CR2 in high voltage module
- Gain degradation of pass transistor in linear regulator (A2-Q2)
- Partial short of bias diodes in semiconductor module, A2-CR20 and A2-CR21
- Partial short of output filter capacitor, C16
- Partial short of linear regulator filter capacitor, C8

The coiled heater is made of tungsten wire which is cataphoritically coated with aluminum oxide. The heater is encased in a split cup made of aluminum oxide. One end of the heater is spot welded to the cathode body. The other end of the heater passes through a small diameter hole in the aluminum oxide cup, then through a larger diameter hole in the metallic heat shield, and is spot welded to a tab on a cross-member which connects to the heater ring on the gun body. The critical portions of this assembly are illustrated in Figure 9. From an examination of the geometry, it appears the only likelihood of a short of any significance is where the heater lead passes through the aluminum heat shield. Contact at this point, sufficient to cut through the aluminum oxide coating, could result in a non-impedance short. However, the possibility of this type of short is very remote, particularly since the clearance hole in the metallic heat shield is specifically made larger than the matching hole in the aluminum oxide cup. This situation, supported by the lack of previous failures of this heater assembly, was judged to be a very unlikely source of the orbit anomaly.

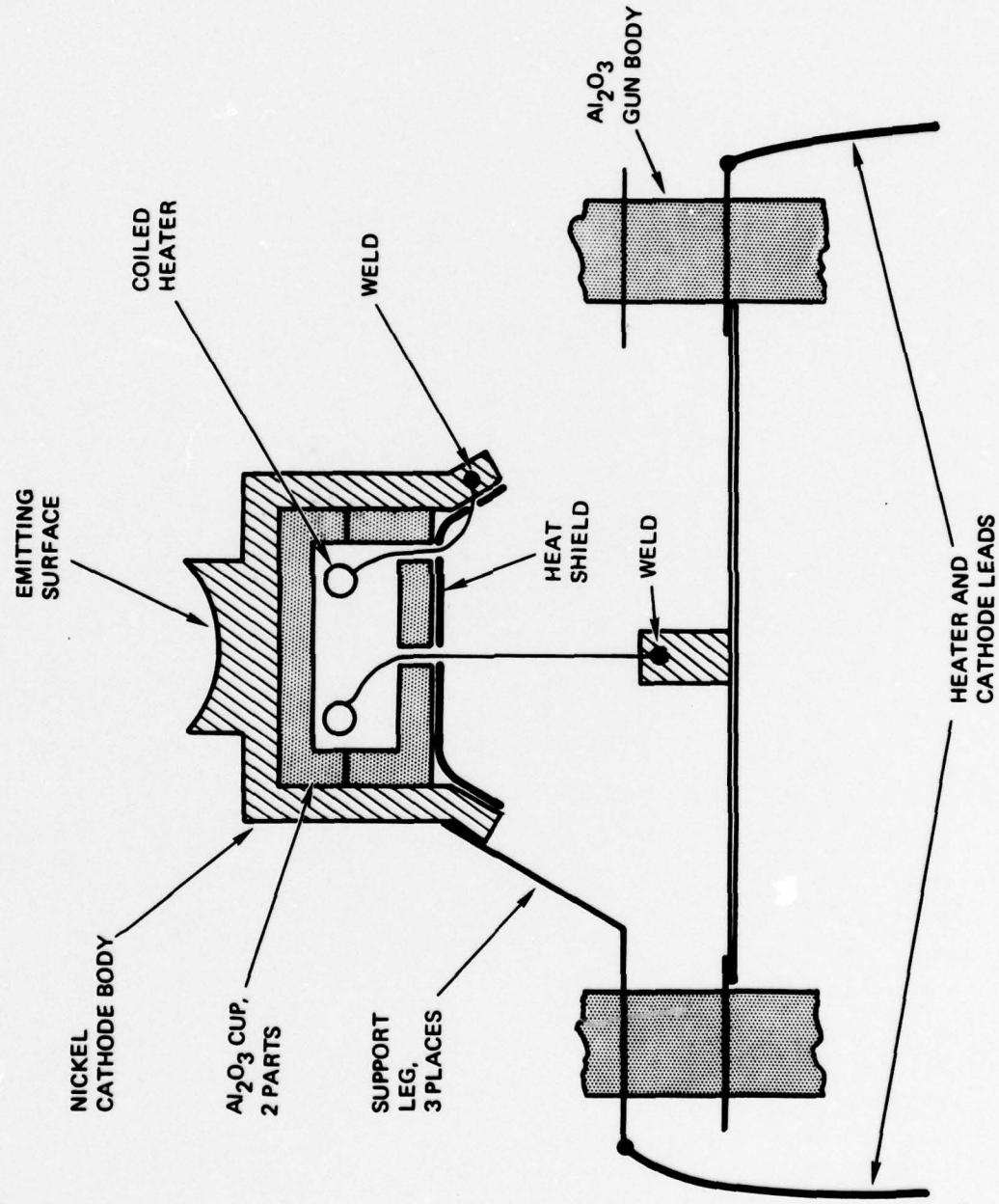


Figure 9. Cross-Section of Heater-Cathode Assembly. (The critical part of the assembly is the point where the heater lead passes through the aluminum heat shield.)

The rectifier diodes (CR1 and CR2) are IN 5417s built to JANTX requirements and upgraded to JANTXV parts at the vendor's. No irregularities existed in the component test data. These diodes are metallurgically bonded, and no potential defects were observed in the DPA sample.

The first components selected for analysis in the semiconductor modules were the pass transistors in the linear regulator (A2-Q2). This device, a 2N2907A, is bought as a JANTXV part. The component test data and DPA on the lot of these devices used in this build of LLWTAs were excellent, with no irregularities. In addition, the vendor reports no known failure history of this type of part.

The bias diodes (A2-CR20 and A2-CR21) in the semiconductor module are IN4148s bought as JANTX parts and upgraded to JANTXV standards by the vendor. These diodes are a compression contact rather than metallurgically bonded design and are subject to some misalignment. However, it was concluded that the upgrading inspection and X-ray process has removed any badly aligned diodes and tilted dice so that shorting or partial shorting of these parts as a failure mode is remote.

Two capacitors were also investigated. One (C8) is the output filter capacitor on the heater voltage source to the TWT, and the other (A2-C16) the output filter capacitor on the linear regulator. A partial short of either one, if stabilized at the proper equivalent resistance, could cause the orbit anomaly. Both of these are tantalum capacitors, one a solid tantalum (C16) and the other a sintered mode (wet slug) polarized tantalum capacitor. The screening and DPA data for C16 showed no anomalous or non-typical indications. Hence, a failure of this part would appear very unlikely.

The second capacitor type (C8) had one device of the 12 used for lot qualification show a higher than specified (1.8 ma versus 1 ma) leakage current after an 8-hour vibration exposure. However, during the subsequent life test (2,000 hours), the leakage current values were within specified limits. Since the leakage current remained low during the life test, it was concluded that vibration is not a cause for device failure or reason for concern.

The manufacturing data package for the failed LLTWA was reviewed in detail to determine whether some irregularity had occurred during the buildup and

ground testing which could possibly explain the orbit failure. Although the data packages documented various squawks and associated rework activities, the corrective actions taken at the time by the TWTa manufacturer seemed appropriate. There was no reason to feel that this TWTa had not been built and tested properly.

5. CONCLUSIONS

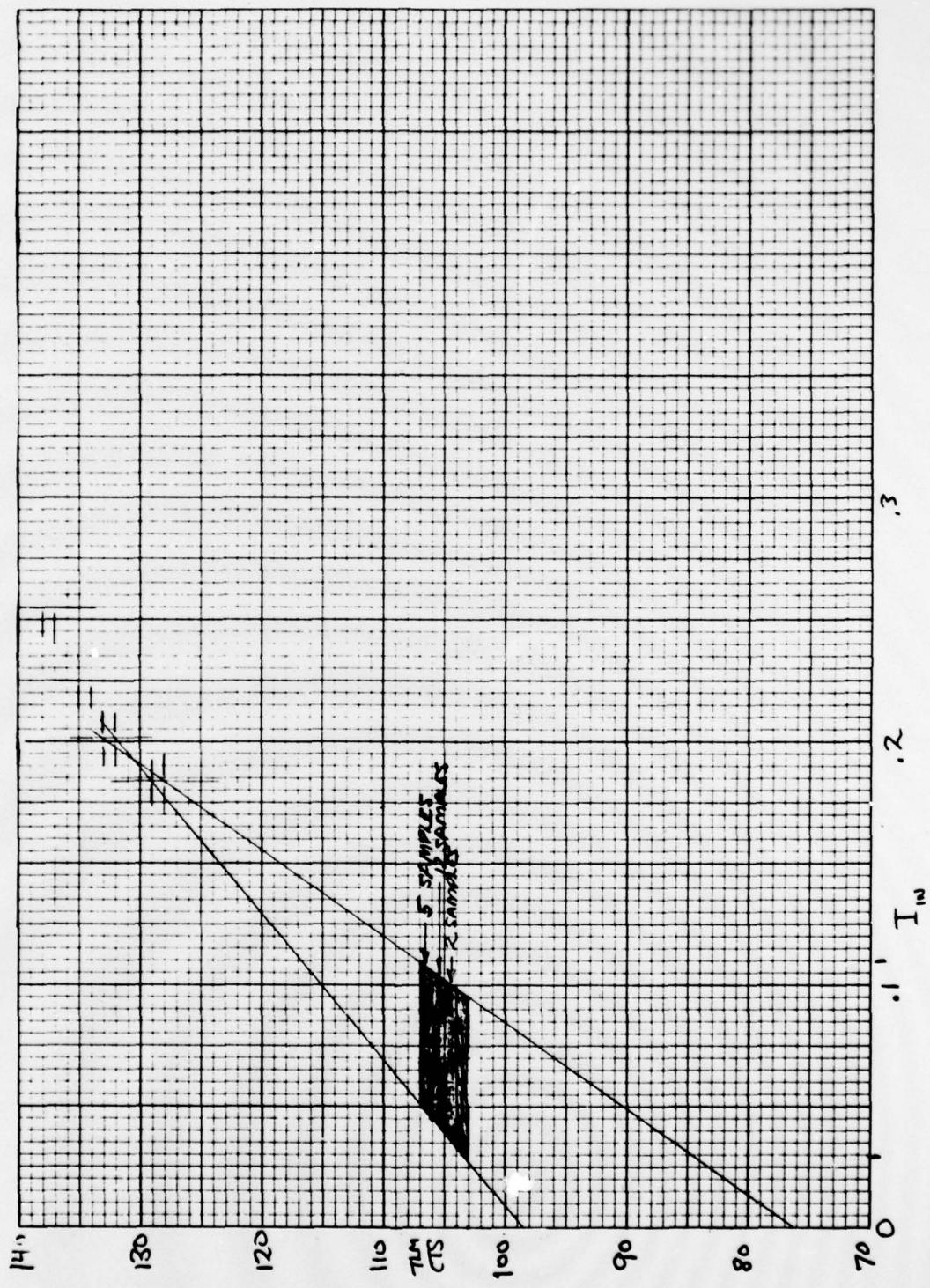
Because it was possible to contrive several different failure modes which yielded signatures similar to the limited satellite telemetry data, it was not possible to pinpoint one specific cause for the orbit anomaly. However, all evidence at hand indicated the failure had occurred somewhere in the TWT heater or the heater power supply. This includes either the linear regulator, the DC to DC converter, or the TWT heater. The piece part failures which most closely fit the flight telemetry signatures are: a partial short of bias diode CR20 or CR21, a change in value of R6, or a gain reduction in Q2 or any parasitic path which effectively results in the same degradation of the linear regulator circuit in the semiconductor module. Each individual failure mode which could have caused this anomaly was judged to be extremely remote. Also, no evidence was found which would indicate there was any sort of defect in the F8 LLTWTAs or any of the units in inventory for F9 through F12. The conclusion is that this failure should be considered isolated in nature, not subject to repeat. No corrective action for the LLTWTAs in inventory for F9 through F12 is recommended.

APPENDIX A
LLTWTA TELEMETRY CALIBRATION DATA

9438 SCF Calibration Curves - No. 2 NCLLTWTA

<u>SubC</u>	<u>WORD</u>	<u>SLOPE</u> CNTS Value	<u>Parameter</u>	<u>REMARKS</u>
3	30	0 -.447 132 .213 255 1.511	NCLL2I (Input Current) AMPS	2 segments 1 st = 5.10ma/CNT 2 nd = 10.55ma/CNT ON-ORBIT and I _{ET} calcs are the same
3	46	139 2.505 255 10.54	NCLLK1 (Cathode Current) millamps	1 segment slope = .06923ma/ cnt
				This segment is the same as I _{ET} . Below 139 CNTS, the slope does not follow the I _{ET} cal curve
3	62	0 1355 255 2161	NCLLHV (Helix Voltage) Volts	1 segment slope = 3.148V/CNT Same as I _{ET} cal curve
4	7	0 -.077 255 1.354	NCLLHI (Helix Current) milliamps	1 segment slope = 5.588ma/ cnt Same as I _{ET} cal curve
4	10	160 3.301 255 4.509	NCLLFU (Filament Voltage) Volts	1 segment slope = .01285V/ cnt This segment is the same as I _{ET} . Below 160cnt, the slope does not follow the I _{ET} cal curve

Uncertainty Analysis - LLTWA Input Current TLM Calibration



HUGHES

ELECTRON DYNAMICS DIVISION

DATA SHEET NO. DSB200302-410

REV. A

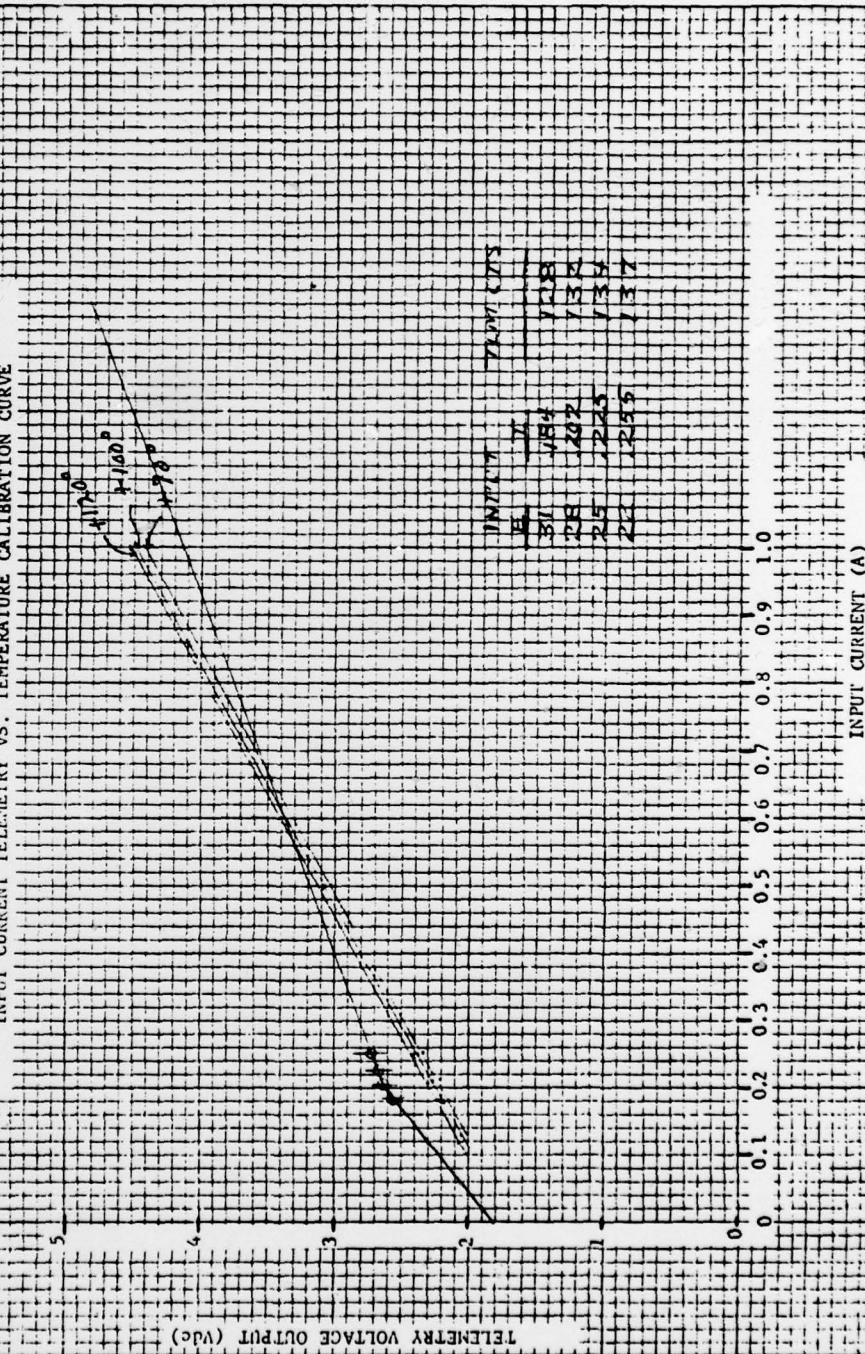
SERIAL NO. 016

PAGE 14 OF 21

TEST DATA SHEET

INPUT CURRENT TELNETRY VS. TEMPERATURE CALIBRATION CURVE

TELNETRY VOLTAGE OUTPUT (Vdc)



CALFILE ID: FILE8 CREAT DATE 11/ 22/ 76

PAGE NCLL UNIT AMPS

F11 3 30 NC 8 LL INPUT 1

CT	0	1	2	3	4	5	6	7	8	9
00000	-0.447	-0.442	-0.437	-0.432	-0.427	-0.422	-0.417	-0.412	-0.407	-0.402
00100	-0.397	-0.392	-0.387	-0.382	-0.377	-0.372	-0.367	-0.362	-0.357	-0.352
00200	-0.347	-0.342	-0.337	-0.332	-0.327	-0.322	-0.317	-0.312	-0.307	-0.302
00300	-0.297	-0.292	-0.287	-0.282	-0.277	-0.272	-0.267	-0.262	-0.257	-0.252
00400	-0.247	-0.242	-0.237	-0.232	-0.227	-0.222	-0.217	-0.212	-0.207	-0.202
00500	-0.197	-0.192	-0.187	-0.182	-0.177	-0.172	-0.167	-0.162	-0.157	-0.152
00600	-0.147	-0.142	-0.137	-0.132	-0.127	-0.122	-0.117	-0.112	-0.107	-0.102
00700	-0.097	-0.092	-0.087	-0.082	-0.077	-0.072	-0.067	-0.062	-0.057	-0.052
00800	-0.047	-0.042	-0.037	-0.032	-0.027	-0.022	-0.017	-0.012	-0.007	-0.002
00900	0.002	0.007	0.012	0.017	0.022	0.027	0.032	0.037	0.042	0.047
01000	0.022	0.057	0.062	0.067	0.072	0.077	0.082	0.087	0.092	0.097
01100	0.102	0.107	0.112	0.117	0.122	0.127	0.132	0.138	0.143	0.148
01200	0.153	0.158	0.163	0.168	0.173	0.178	0.183	0.188	0.193	0.198
01300	0.203	0.208	0.213	0.215	0.226	0.237	0.247	0.258	0.269	0.279
01400	0.290	0.300	0.311	0.322	0.332	0.343	0.354	0.364	0.375	0.385
01500	0.396	0.407	0.417	0.428	0.438	0.449	0.460	0.470	0.481	0.492
01600	0.502	0.513	0.523	0.534	0.545	0.555	0.566	0.577	0.587	0.598
01700	0.608	0.619	0.630	0.640	0.651	0.662	0.672	0.683	0.693	0.704
01800	0.712	0.725	0.736	0.746	0.757	0.768	0.778	0.789	0.800	0.810
01900	0.821	0.831	0.842	0.853	0.863	0.874	0.885	0.895	0.906	0.916
02000	0.927	0.938	0.948	0.959	0.969	0.980	0.991	1.001	1.012	1.023
02100	1.033	1.044	1.054	1.065	1.076	1.086	1.097	1.108	1.118	1.129
02200	1.139	1.150	1.161	1.171	1.182	1.193	1.203	1.214	1.224	1.235
02300	1.246	1.256	1.267	1.277	1.288	1.299	1.309	1.320	1.331	1.341
02400	1.352	1.362	1.373	1.384	1.394	1.405	1.416	1.426	1.437	1.447
02500	1.458	1.469	1.479	1.490	1.500	1.511				

CALFILE ID FLTR8 CREATE DATE 11/ 22/ 76

PAGE# NC#LL UNIT VOLTS

FL 1 3 62 NC B II HFLIX V

0377

CT	0	1	2	3	4	5	6	7	8	9
0000	1355.	1358.	1362.	1365.	1368.	1371.	1374.	1377.	1384.	
0010	1387.	1390.	1393.	1396.	1400.	1403.	1406.	1409.	1412.	1415.
0020	1418.	1422.	1425.	1428.	1431.	1434.	1437.	1441.	1444.	1447.
0030	1450.	1453.	1456.	1460.	1463.	1466.	1469.	1472.	1475.	1478.
0040	1482.	1485.	1488.	1491.	1494.	1497.	1501.	1504.	1507.	1510.
0050	1513.	1516.	1520.	1523.	1526.	1529.	1532.	1535.	1538.	1542.
0060	1545.	1548.	1551.	1554.	1557.	1561.	1564.	1567.	1570.	1573.
0070	1576.	1580.	1583.	1586.	1589.	1592.	1595.	1598.	1602.	1605.
0080	1608.	1611.	1614.	1617.	1621.	1624.	1627.	1630.	1633.	1636.
0090	1641.	1643.	1646.	1649.	1652.	1655.	1658.	1662.	1665.	1668.
0100	1671.	1674.	1677.	1681.	1684.	1687.	1690.	1693.	1696.	1700.
0110	1703.	1706.	1709.	1712.	1715.	1718.	1721.	1725.	1728.	1731.
0120	1734.	1737.	1741.	1744.	1747.	1750.	1753.	1756.	1760.	1763.
0130	1766.	1769.	1772.	1775.	1778.	1782.	1785.	1788.	1791.	1794.
0140	1797.	1801.	1804.	1807.	1810.	1813.	1816.	1820.	1823.	1826.
0150	1829.	1832.	1835.	1838.	1842.	1845.	1848.	1851.	1854.	1857.
0160	1861.	1864.	1867.	1870.	1873.	1876.	1880.	1883.	1886.	1889.
0170	1892.	1895.	1898.	1902.	1905.	1908.	1911.	1914.	1917.	1921.
0180	1924.	1927.	1930.	1933.	1936.	1940.	1943.	1946.	1949.	1952.
0190	1952.	1958.	1962.	1965.	1968.	1971.	1974.	1977.	1981.	1984.
0200	1987.	1990.	1993.	1996.	2000.	2003.	2006.	2009.	2012.	2015.
0210	2018.	2022.	2025.	2028.	2031.	2034.	2037.	2041.	2044.	2047.
0220	2050.	2053.	2056.	2060.	2063.	2066.	2069.	2072.	2075.	2078.
0230	2082.	2085.	2088.	2091.	2094.	2097.	2101.	2104.	2107.	2110.
0240	2113.	2116.	2120.	2123.	2126.	2129.	2132.	2135.	2138.	2142.
0250	2145.	2148.	2151.	2154.	2157.	2161.				

HUGHES ELECTRON DYNAMICS DIVISION

McDonnell Douglas Corporation

TEST DATA SHEET

DATA SHEET NO. RD-5
REV. A

SERIAL NO. 016
PAGE 20 OF 21

CATHODE VOLTAGE TELEMETRY VS. TEMPERATURE CALIBRATION CURVE

$I_m = 0.50$ mA

TELEMETRY VOLTAGE OUTPUT (Vdc)

CATHODE VOLTAGE (V)

CALFILE ID: FLTR CREATE DATE 11/22/76

PAGE: NCLL UNIT: MA

FL 1 4 7 NC B LL HFLIX I 0377

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0010	-0.021	-0.015	-0.010	-0.004	0.001	0.006	0.012	0.017	0.023	0.029
0020	0.034	0.040	0.046	0.051	0.057	0.062	0.068	0.074	0.079	0.085
0030	0.090	0.096	0.102	0.107	0.113	0.119	0.124	0.130	0.135	0.141
0040	0.147	0.152	0.158	0.163	0.169	0.175	0.180	0.186	0.192	0.197
0050	0.203	0.208	0.214	0.220	0.225	0.231	0.236	0.242	0.248	0.253
0060	0.259	0.264	0.270	0.276	0.281	0.287	0.293	0.298	0.304	0.309
0070	0.315	0.321	0.326	0.332	0.337	0.343	0.349	0.354	0.360	0.366
0080	0.371	0.377	0.382	0.388	0.394	0.399	0.405	0.410	0.416	0.422
0090	0.427	0.433	0.439	0.444	0.450	0.455	0.461	0.467	0.472	0.478
0100	0.483	0.489	0.495	0.500	0.506	0.512	0.517	0.523	0.528	0.534
0110	0.540	0.545	0.551	0.556	0.562	0.568	0.573	0.579	0.585	0.590
0120	0.596	0.601	0.607	0.613	0.618	0.624	0.629	0.635	0.641	0.646
0130	0.652	0.658	0.663	0.669	0.674	0.680	0.686	0.691	0.697	0.702
0140	0.708	0.714	0.719	0.725	0.731	0.736	0.742	0.747	0.753	0.759
0150	0.764	0.770	0.775	0.781	0.787	0.792	0.798	0.804	0.809	0.815
0160	0.820	0.826	0.832	0.837	0.843	0.848	0.854	0.860	0.865	0.871
0170	0.877	0.882	0.888	0.893	0.899	0.905	0.910	0.916	0.921	0.927
0180	0.933	0.938	0.944	0.950	0.955	0.961	0.966	0.972	0.978	0.983
0190	0.989	0.994	1.000	1.006	1.011	1.017	1.023	1.028	1.034	1.039
0200	1.042	1.051	1.056	1.062	1.067	1.073	1.079	1.084	1.090	1.096
0210	1.101	1.107	1.112	1.118	1.124	1.129	1.135	1.140	1.146	1.152
0220	1.157	1.163	1.169	1.174	1.180	1.185	1.191	1.197	1.202	1.208
0230	1.213	1.219	1.225	1.230	1.236	1.242	1.247	1.253	1.258	1.264
0240	1.270	1.275	1.281	1.286	1.292	1.298	1.303	1.309	1.315	1.320
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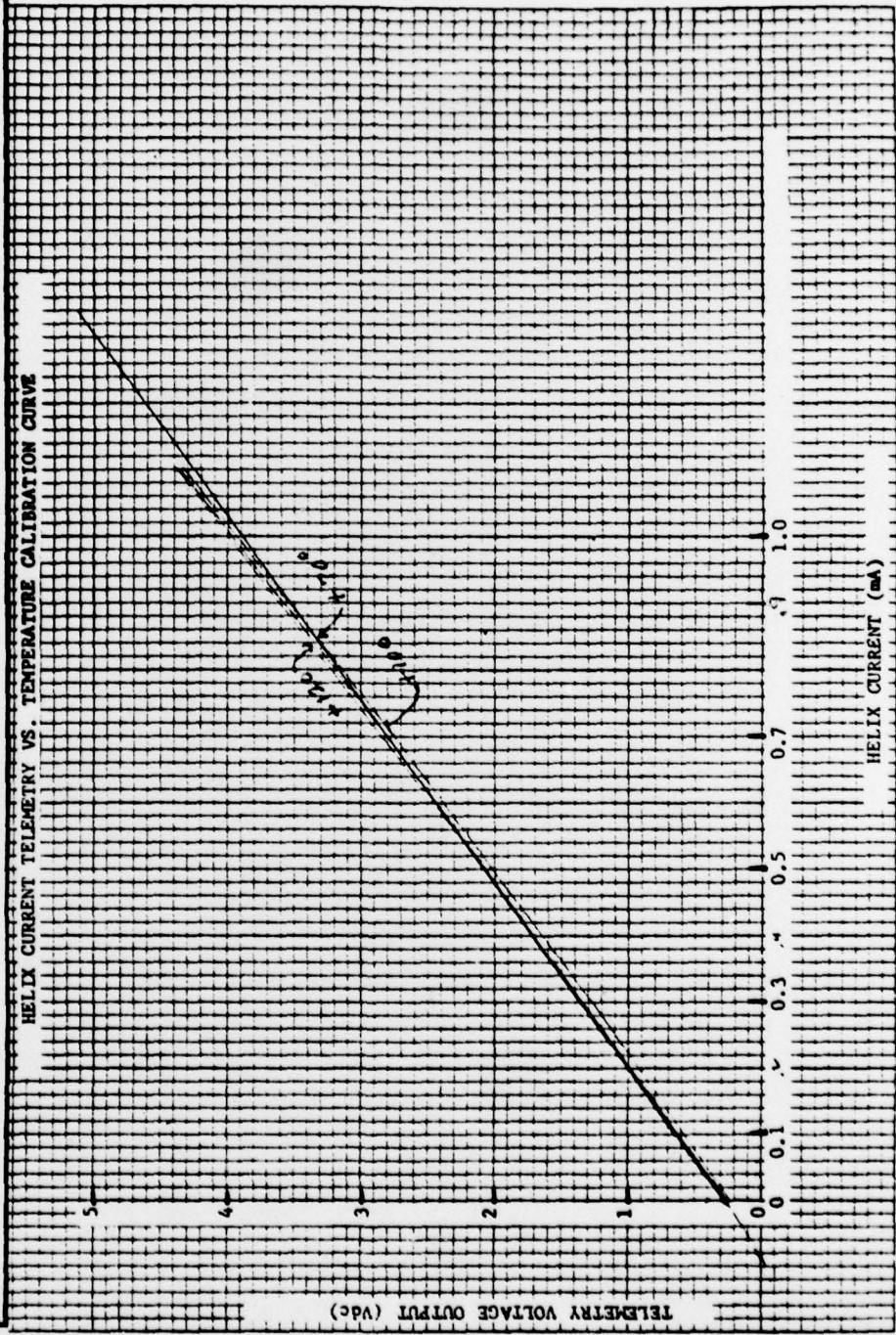
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HUGHES ELECTRON DYNAMICS DIVISION

GENERAL ELECTRIC COMPANY

TEST DATA SHEET

DATA SHEET NO. DS 8200-J2-A10
REV. A
SERIAL NO. 016
PAGE 17 OF 21



CAI FILE ID: FILTER CREATE DATE 11/22/76

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F113 46 NC B LL CATH 1

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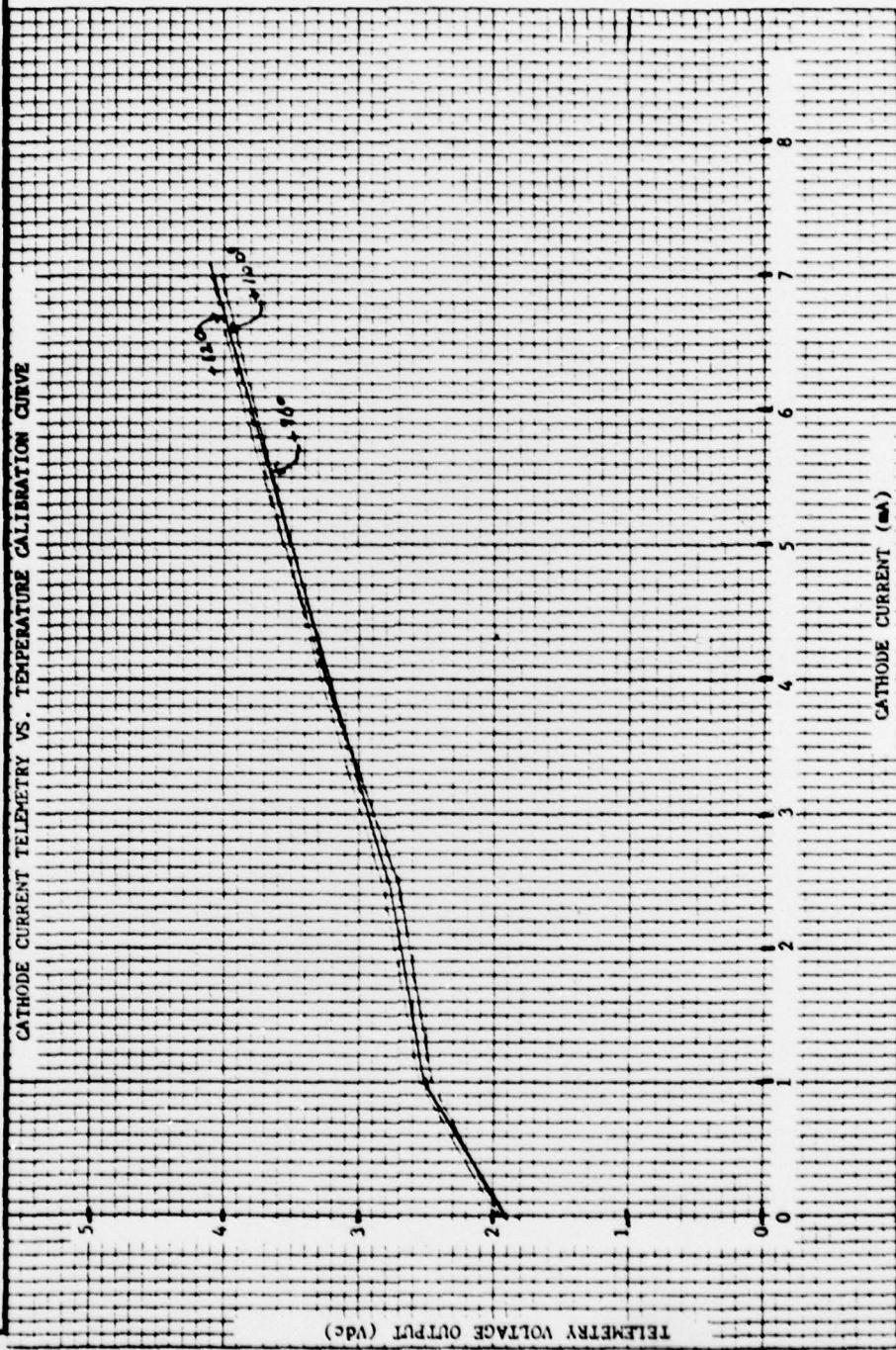
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00100	-2.833	-2.799	-2.766	-2.733	-2.699	-2.666	-2.633	-2.600	-2.566	-2.533
00200	-2.500	-2.466	-2.433	-2.400	-2.366	-2.333	-2.300	-2.266	-2.233	-2.200
00300	-2.166	-2.133	-2.100	-2.066	-2.033	-2.000	-1.966	-1.933	-1.900	-1.866
00400	-1.833	-1.800	-1.766	-1.733	-1.700	-1.666	-1.633	-1.600	-1.566	-1.533
00500	-1.500	-1.466	-1.433	-1.400	-1.366	-1.333	-1.300	-1.266	-1.233	-1.200
00600	-1.167	-1.133	-1.100	-1.067	-1.033	-1.000	-0.967	-0.933	-0.900	-0.867
00700	-0.833	-0.800	-0.767	-0.733	-0.700	-0.667	-0.633	-0.600	-0.567	-0.533
00800	-0.500	-0.467	-0.433	-0.400	-0.367	-0.333	-0.300	-0.267	-0.233	-0.200
00900	-0.167	-0.133	-0.100	-0.067	-0.033	-0.000	0.032	0.066	0.099	0.132
01000	0.163	0.199	0.232	0.265	0.299	0.332	0.365	0.399	0.432	0.465
01100	0.499	0.532	0.565	0.599	0.632	0.665	0.699	0.732	0.765	0.799
01200	0.832	0.865	0.899	0.932	0.965	0.999	1.111	1.219	1.326	1.433
01300	1.540	1.647	1.754	1.862	1.969	2.076	2.183	2.290	2.398	2.505
01400	2.272	2.645	2.714	2.783	2.853	2.922	2.991	3.060	3.130	3.199
01500	3.268	3.337	3.407	3.476	3.545	3.615	3.684	3.753	3.822	3.892
01600	3.961	4.030	4.100	4.169	4.238	4.307	4.377	4.446	4.515	4.584
01700	4.624	4.723	4.792	4.862	4.931	5.000	5.069	5.139	5.208	5.277
01800	5.346	5.416	5.485	5.554	5.624	5.693	5.762	5.831	5.901	5.970
01900	6.039	6.108	6.178	6.247	6.316	6.386	6.455	6.524	6.593	6.663
02000	6.732	6.801	6.871	6.940	7.009	7.079	7.148	7.217	7.286	7.355
02100	7.425	7.494	7.563	7.633	7.702	7.771	7.840	7.910	7.979	8.048
02200	8.117	8.187	8.256	8.325	8.395	8.464	8.533	8.602	8.672	8.741
02300	8.810	8.879	8.949	9.018	9.087	9.157	9.226	9.295	9.364	9.434
02400	9.503	9.572	9.641	9.711	9.780	9.849	9.919	9.988	10.05	10.12
02500	10.19	10.26	10.33	10.40	10.47	10.54				

HUGHES ELECTRONIC CORPORATION

HUGHES

DATA SHEET NO. DSB200302-410
REV. A
SERIAL NO. 016

TEST DATA SHEET



CALFILE IN FLTR CREATE DATE 11/22/76

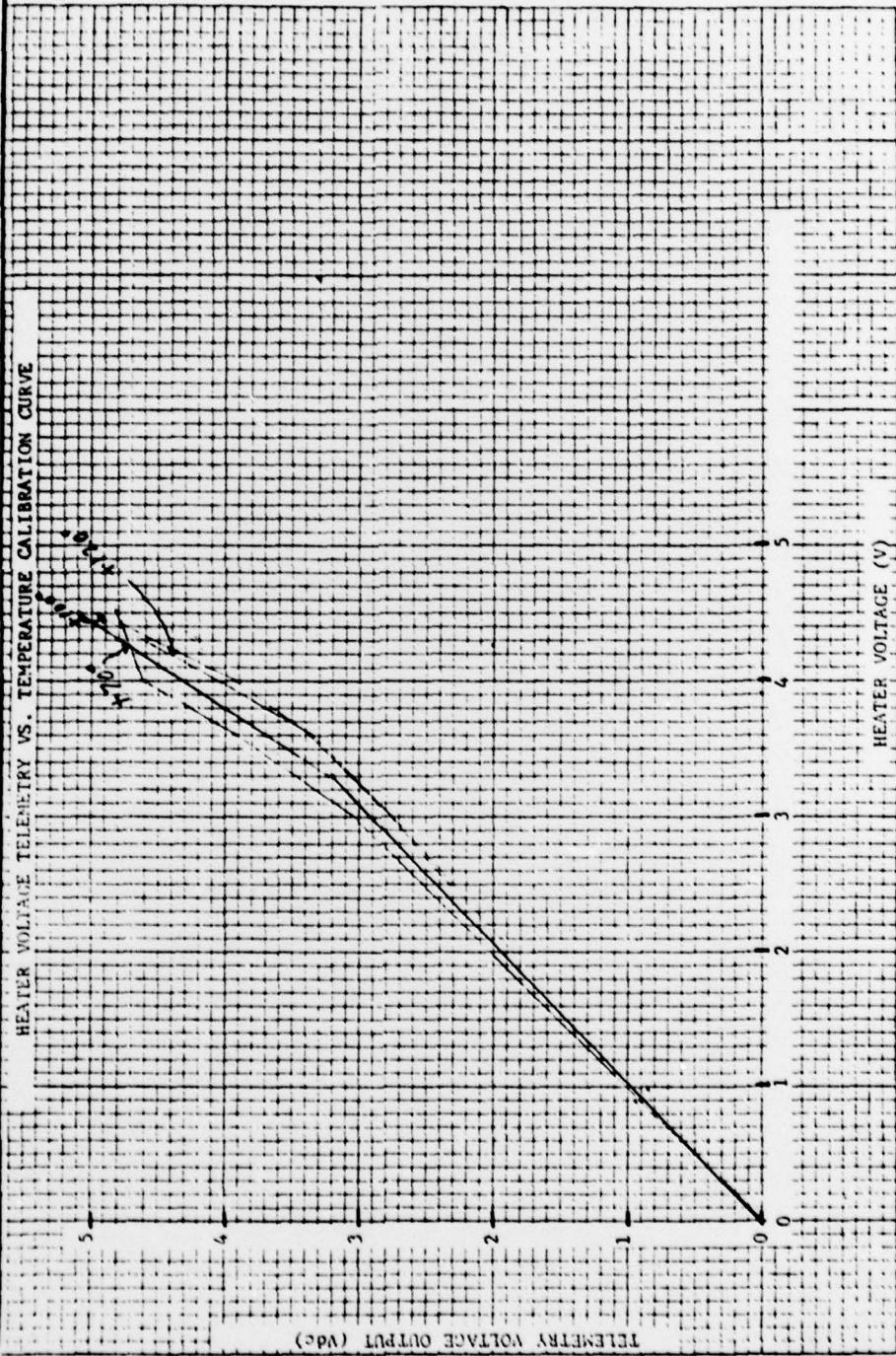
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0020	0.430	0.451	0.473	0.494	0.516	0.537	0.559	0.580	0.602	0.623	
0030	0.645	0.666	0.687	0.709	0.730	0.752	0.773	0.795	0.816	0.838	
0040	0.859	0.881	0.902	0.924	0.945	0.967	0.988	1.010	1.031	1.053	
0050	1.074	1.096	1.117	1.139	1.160	1.182	1.203	1.225	1.246	1.268	
0060	1.289	1.311	1.332	1.354	1.375	1.396	1.418	1.439	1.461	1.482	
0070	1.504	1.525	1.547	1.568	1.590	1.611	1.633	1.654	1.676	1.697	
0080	1.719	1.740	1.762	1.783	1.805	1.826	1.848	1.869	1.891	1.912	
0090	1.934	1.955	1.977	1.998	2.020	2.041	2.062	2.084	2.105	2.127	
0100	2.148	2.170	2.191	2.213	2.234	2.256	2.277	2.299	2.320	2.342	
0110	2.363	2.385	2.406	2.428	2.449	2.471	2.492	2.514	2.535	2.557	
0120	2.578	2.600	2.621	2.643	2.664	2.686	2.707	2.729	2.750	2.771	
0130	2.793	2.814	2.836	2.857	2.879	2.900	2.922	2.943	2.965	2.986	
0140	3.008	3.029	3.051	3.072	3.094	3.115	3.137	3.158	3.180	3.201	
0150	3.223	3.244	3.266	3.287	3.309	3.330	3.352	3.373	3.395	3.416	
0160	3.437	3.459	3.480	3.502	3.517	3.533	3.548	3.563	3.578	3.593	
0170	3.608	3.624	3.639	3.654	3.669	3.684	3.699	3.715	3.730	3.745	
0180	3.760	3.775	3.790	3.806	3.821	3.836	3.851	3.866	3.881	3.897	
0190	3.912	3.927	3.942	3.957	3.972	3.988	4.003	4.027	4.037	4.046	
0200	4.056	4.066	4.075	4.085	4.095	4.104	4.114	4.124	4.134	4.143	
0210	4.153	4.163	4.172	4.182	4.192	4.202	4.211	4.221	4.231	4.240	
0220	4.250	4.260	4.269	4.279	4.289	4.299	4.308	4.318	4.328	4.337	
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0240	4.444	4.454	4.464	4.473	4.483	4.493	4.502	4.512	4.522	4.531	
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HUGHES

ELECTRON DYNAMICS DIVISION

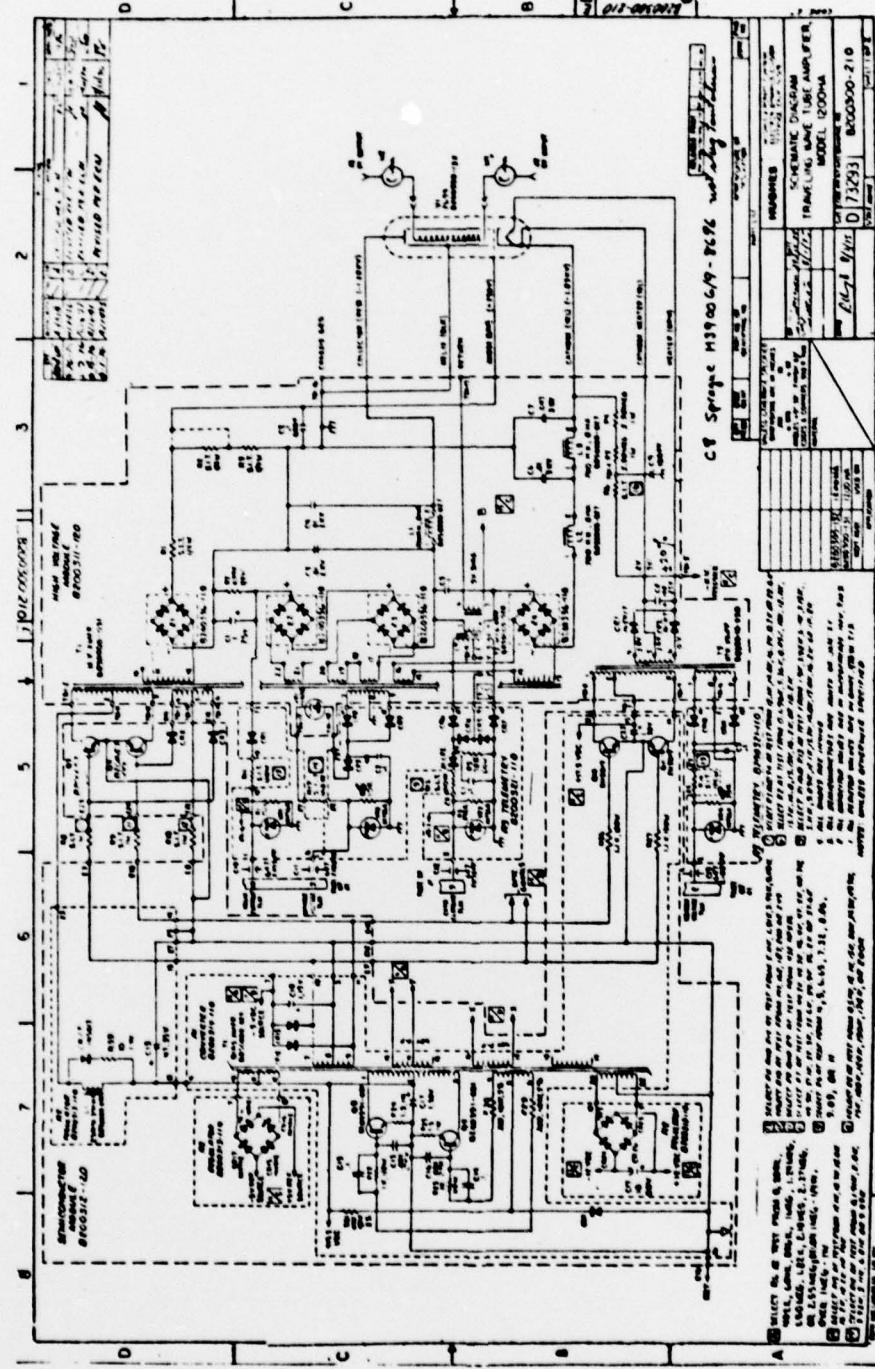
TEST DATA SHEET

DATA SHEET NO. DSB200302-410
REV. A
SERIAL NO. 016
PAGE 16 OF 21

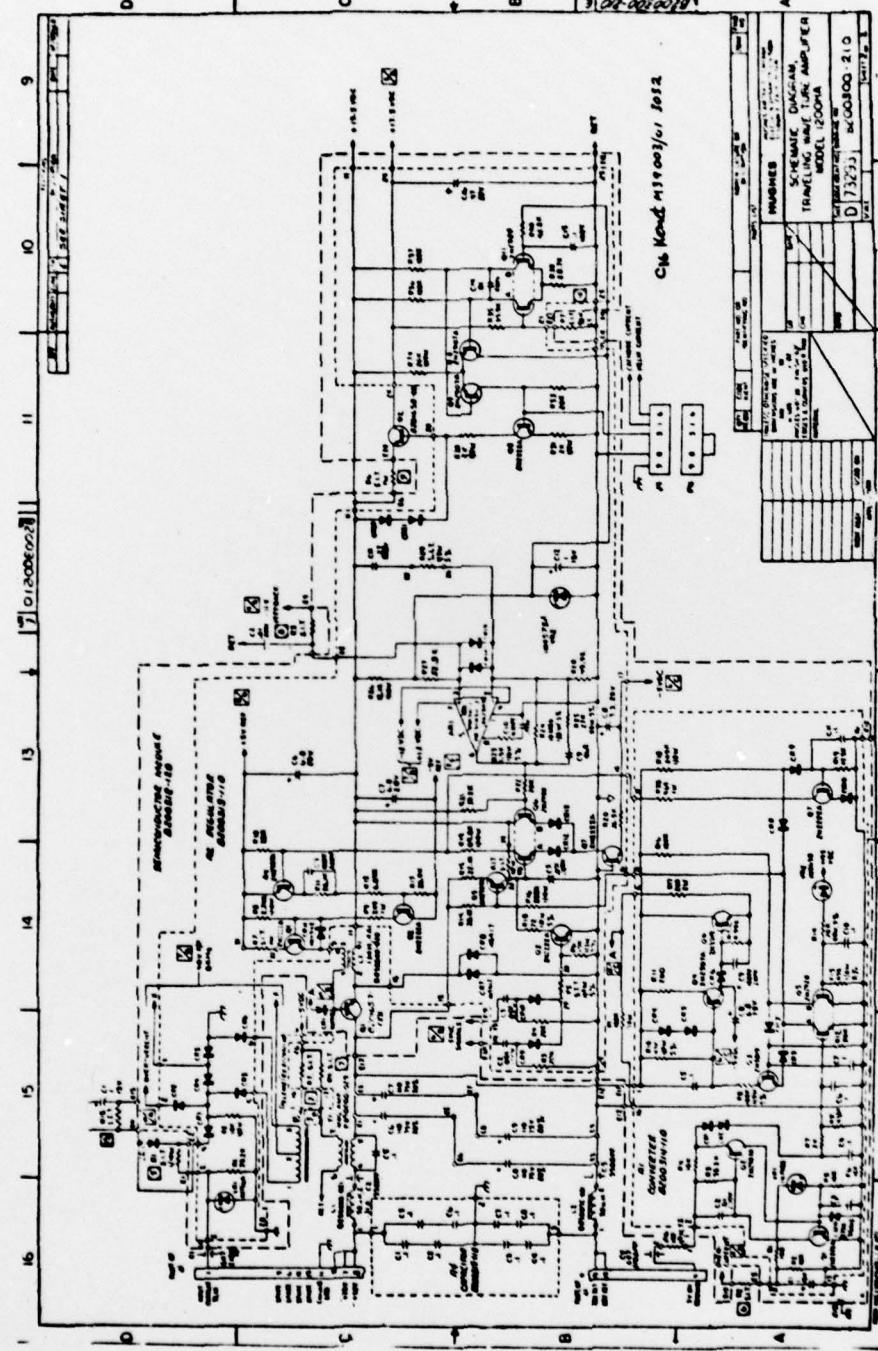


APPENDIX B

LLTWTA SCHEMATIC



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